टीएचडीसी इंडिया लिमिटेड
THDC INDIA LIMITED

Engineering Geology Handbook

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टीएचडीसी इंडिया लिमिटेड
THDC INDIA LIMITED
(A joint venture of Govt. of India & Govt. of UP)
Geology & Geotechnical Department
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Designation.......................................Employee No. ....

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(भारत सरकार एवं उ.प्र.सरकार का संयुक्त उपक्रम)
(A Joint venture of Govt. of India & Govt. of UP)
CIN : U45203UR1988GOI009822

FOREWORD

With the vision of "A world class energy entity" THDCIL is engaged in planning and developing various hydro power projects and other sources of energy. The accurate knowledge and rich experience of Rock Engineering therefore, becomes inevitable to cater to the requirements of design and construction activities of such projects. This is more so in the Himalayan region of the country. Geology and Geotechnical Department of THDCIL is involved in number of assignments related to geological and geotechnical aspects of various projects. In order to keep pace with the recent developments in research and field practices, knowledge about the engineering characteristics of geological media becomes important. For the characterization of the rock and rock masses in uniform manner for safe and economic design of structures, it is required to follow certain standards. Keeping this in view, I am happy to see that Geology and Geotechnical Department has prepared an **"Engineering Geology Handbook"** having referred BIS Codes, ISRM Guidelines, Standard Practices, Geotechnical Field Diary of NHPC etc. This field diary would be very useful for the Geologists and Geo-technical Engineers of THDCIL.

(D.V. Singh)
Chairman & Managing Director

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Regd. Office: Bhagirathi Bhawan, (Top Tarrace), Bhagirathipuram, Tehri Garhwal-249 001
टेलीफैक्स- 0135-2439463, Telefax: 0135-2439463, Website Adress: www.thdc.gov.in
("हिन्दी को राजभाषा बनाना, भाषा का प्रश्न नहीं अपितु देशाभिमान का प्रश्न है")

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MESSAGE

Execution of river valley projects, particularly in young and fragile Himalayan geological complex conditions, extensive geological mapping and explorations are required before hand to deliver any hydroelectric projects within stipulated time and cost. A great variety of methods and materials have been developed by various national and internationally renowned agencies like Bureau of Indian Standard (BIS), Geological Survey of India (GSI), NIRM, British code of practices etc. to prepare the geological maps, conduct the lab tests, and explorations at various stages of projects which have been compiled in this Engineering Geology Handbook.

This Hand book would play a vital role of practical guide to engineers, geologists and others involved in the planning, design and implementation of exploration programs. Its primary purpose is to provide hands-on document for preparing geological maps, lab / field investigation fundamentals and practical specifications and field procedures for explorations.

It is hoped that the need for a pragmatic, hands-on reference document would be met by this handbook, which is intended to bridge the gap between the existing technical literature and the applications as presently practiced in the field.

I am sure that this handbook will be a great asset of THDCIL and would like to appreciate the efforts put in by Geology and Geotechnical department in preparing the Engineering Geology Handbook.

(H.L. Arora)

Director-Technical

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ACKNOWLEDGEMENT

THDCIL have been commissioned Tehri HEP (4X250 MW) and Koteshwar HEP (4X100 MW). Other hydro power projects namely VPHEP, Tehri PSP, Dhukwan SHEP etc. are under construction stage presently and some others are under various stages of project. While working in the projects, the need was felt to have a compendium of all the materials and methods which have been developed by various national and internationally renowned agencies like Bureau of Indian Standard (BIS), Geological Survey of India (GSI), ISRM, NHPC, NIRM, British Code of Practices etc. to prepare the geological maps, conduct the lab tests, and explorations at various stages of projects. Engineering Geology Handbook comprised with the preview of all the above standards and guidelines as hands-on reference document.

The Engineering Geology Handbook has been prepared with the consistent efforts of Geology and Geotechnical department incorporating the recommendations provided time to time by Dr. P.C. Nawani, Consultant (Geology), THDC India Limited.

I am extremely grateful to Shri. D. V. Singh, CMD for providing opportunities to compiled such work and allowed publishing Engineering Geology Handbook. I sincerely thank Shri H. L. Arora, Director (Technical), Shri Vijay Goel, Director (Personnel) for extending their whole hearted support in the entire process.

I am grateful to Shri R. K. Vishnoi, Executive Director, who always available to extend his guidance during the drafting and giving the final shape to the handbook.

I express my gratitude to all Geologists of Geology and Geotechnical department for their tireless efforts for contributing towards handbook. They really deserve all praise for their outstanding commitment.

Last but not the least I would like to express our gratitude to all THDCIL staff that have rendered the secretarial support in publication of this handbook.

(Gajendra Singh)
General Manager (Geology & Geotechnical)

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Appendix

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GEOLOGICAL TIME SCALE

RELATIVE GEOLOGICAL TIME				
ERA	**PERIOD**		**EPOCH**	**ATOMIC TIME** (million years)
Cenozoic	Quaternary		Holocene	0.01
			Pleistocene	2.58
	Neogene		Pliocene	5.3
			Miocene	23
	~~Tertiary~~ Paleogene		Oligocene	33.9
			Eocene	56
			Paleocene	66
Mesozoic	Cretaceous		Late	
			Early	145
	Jurassic		Late	
			Middle	
			Early	201
	Triassic		Late	
			Middle	
			Early	252
Paleozoic	Permian		Late	
			Early	299
	Carboniferous	Pennsylvanian	Late	
			Middle	
			Early	
		Mississippian	Late	
			Early	359
	Devonian		Late	
			Middle	
			Early	419
	Silurian		Late	
			Middle	
			Early	444
	Ordovician		Late	
			Middle	
			Early	485
	Cambrian		Late	
			Middle	
			Early	541
Precambrian				~ 4600

Source: International Chronostratigraphic Chart, International Commission on Stratigraphy V 2015/01

ROCK TYPE CLASSIFICATION

GENETIC/GROUP		DETRITAL SEDIMENTARY						PYROCLASTIC		CHEMICAL/ORGANIC
Usual Structure		BEDDED								
Composition		Grain of rock, quartz, feldspar and clay minerals			At least 50% of grains are of carbonate			At least 50% of grains are of Fin-grained igeous rock		
GRAIN SIZE (mm) 60 / 2	Very coarse-grained / Coarse-grained	RUDACEOUS	GRAINS are mainly minerals fragments: BOULDERS COBBLES; GRAVEL	Rounded Grains: CONGLOMERATE Angular Grains: BRECCIA	CARBON-ATE GRAVEL	CALCI-RUDITE	LIMESTONE and DOLOMITE (Undifferentiated)	Rounded grains AGGLOMERATE Angular grains VOCANIC BRECCIA LAPILLITUFF	VOLCANIC ASH	SALINE ROCKS Halite Anhydrite; Gypsum; LIME STONE
	Medium Grained	ARDACEOUS	GRAINS are mainly minerals fragments: SAND STONE: Grains are mainly minerals fragments; QUARZ SANDSTONE: 95% Quartz, voids empty or cemented; ARKOSE: 75% Quartz, up to 25%, feldspar void empty or cemented.; GREYWACKE: 75% feldspar fragments		CORBON-ATE SAND	CALC-ARENITE		TUFF		DOLOMITE; CHERT; FLINT
0.06	Fine - grained	ARGILIACEOUS or LUTACEOUS	SILT; SILT STONE 50% fine grained particles	MUDSTONE SHALE: fissile MUDSTONE; MARLSTONE	CARBONATE SILT	CARBONATE SILT		Fine-grained TUFF		
0.002	Very Fine - grained		CLAY; CLAY STONE 50% Very fine grained particles		CORBON-ATE MUD	CALCILUTITE		Very fine-grained TUFF		PEAT LIGNITE COAL
	GLASSY AMORPHOUS									

METAMORPHIC		IGNEOUS				GENETIC GROUP		
FOLIATED		MASSIVE				Usual structure		
Quartz, feldspars, micas, acicular dark minerals		Light, colored minerals are quartz, feldspar, mica		Dark and light minerals	Dark minerals	composition		
GNEISS (ortho-para-Alternate layer of granular and flaky minerals	MARBLE GRANULITE	Acid rocks	intermediate	Basic rocks	Ultrabasic	Very coarse grained	-60	GRAIN SIZE (MM)
MIGMATITE		PEGMATITE			PYROXENITE and PERIDOTITE SERPENTINITE	Coarse grained	-2	
SCHIST								
PHYLLITE	QUARTZITE HORNFELS AMPHIBLITE	GRANITE	DIORITE	GABBRO		medium grained		
		MICROGANTITE	MICRODIORITE	DOLERITE				
SLATE MYLONITE		RHYOLITE	ANDESITE	BASALT		Fine Grained	-0.06	
						Very fine grained	-0.002	
		OBSIDIAN and PITCHSTONE TECHYLTE				GLASSY AMORPHOUS		
		VOLCANIC GLASSES						

Source: Bulletin of the International Association of Engineering Geology, No. 19, June/July, 1979

RECOMMENDED SCALES FOR GEOLOGICAL AND GEOTECHNICAL MAPPING FOR RIVER VALLEY PROJECTS (IS 15686:2006)

Sl. No.	Project Stage	Description of Geological / Geotechnical Map	Recommended Scale	Contour Interval
(i)	Reconnaissance of Pre-feasibility stage	Satellite imageries/aerial Photographic Studies: a) For selection of dam sites b) For choice of tunnel/channel-alignments c) For regional geological and lineament interpretation. d) For reservoir area geology, mineral occurrences of significance and structural features.	1:50000 or 1:25000	40 or 20
		Regional Geological studies for dam sits, tunnel/channel alignment, powerhouse sites, construction material sites and mineral occurrences of significance.	1:50 000 or 1:25 000	40 or 20
(ii)	Preliminary Investigations or Feasibility Stage	Aerial photographic studies useful adjunct to surface mapping to collect further information about surface conditions around the probable sites selected and to locate the types and characteristic of construction materials.	1:25 000 or 1:10 000	5
		Geological mapping of reservoir, construction material sites and updated geological plan of tunnels/channels.	1:15000 to 1: 10000	1 to 5
		Geological mapping of dam site and appurtenant structure, powerhouse site.	1:5 000	2 to 5
		Logging of exploratory drifts, pits, trenches and drill holes	1:100	-----
(iii)	Details investigation of detailed Project Report Stage	Geological mapping of reservoir area, construction material sites, access roads.	1:2000	1 to 5
		Geological mapping of tunnel/channel alignment, powerhouse site, dam and appurtenant structures.	1:1000	1 to 2
		Geological mapping of areas of special importance in the reservoir like landslides and major structural feature	1:2000 to 1:1000	1 to 2
		Geological mapping of borrow areas and quarry sites.	1:2000 to 1:1 000	1 to 2
		Updated geological plans of dam and ancillary structures, powerhouse areas, critical areas in open channel area	1:1000	1 to 2
		Geological mapping of tunnel portals.	1:500	1 to 2
		Logging /Updating of exploratory drifts, pilot tunnels, pits, trenches and drill holes.	1:100	1
(iv)	Construction Stage	Foundation grade geotechnical mapping of earth and rock fill dam	1:500 to 1:100	1 to 2
		Foundation grade geotechnical mapping of concrete dam blocks, surface and underground powerhouse excavations, tunnels.	1:100	1

Note: The purpose and scale of the map should be duly considered. A regional map may show only generalized formation, contacts and structures. A dam site map focuses attention on greater details in a small area. Ingenuity and sound judgment are essential for presentation of the diverse details required in engineering geology studies.

SYMBOLS AND COLOURS FOR GEOLOGICAL MAPS

SYMBOLS FOR GEOLOGICAL MAPS

Symbols generally refers to structural features like strike and dip of folds, faults etc. that refers to how the rock units are associated. The symbols should be simple, easy to draw, clear to reproducible; a mnemonic for what is represented. Symbols of similar ideas have similar design. In some cases they are content and scale dependent.

Each geological unit is assigned a set of letters to symbolize it on the map. The place where two different geological units are found next to each other is called a contact, and that is represented by different kind of lines on the geological map. The two main types of contacts shown on most geological maps are depositional and faulted contact. The place where line is precisely located is shown as solid, but where the uncertain it is dashed. The lines on the map may be modified by others symbols on the line (triangles, arrows etc.), which gives more information about the line.

COLOURS FOR GEOLOGICAL MAPS

Colours exist in geological maps for practical reasons to carry information in a situation where there is a considerable amount of details is to be presented. An overall goal is to make sure the topographic base style legible. There may be four method of approach more than one of which may be an influence on the colour selected:-

- ❖ Convey outcrop pattern clearly, using colours that are pleasing aesthetically
- ❖ Relate colour to the stratigraphic age of rock (1881 Intl. geological congress)
- ❖ Associate colour with lithology
- ❖ Use of colour that is the same as actual colour of the rock.

Colours are somewhat standardized although some general, acknowledged international conventions is much needed. Remarkable absence of uniformity in the means by which different strata have been represented is still in existence.

In the United States, the USGS set a colour standard for the first national geological map in 1881. The European Geological Community established their own standards latter on. The two major colour systems in use for geological maps are tabled below.

System	American Colour System		International Colour System	
	USGS, 2^{nd} Ann. Rept. 1881	**Geologic Map of United states, 1974**	**2nd and 3rd Intl. Geol. Congress 1881, 1885**	**Geological Map of France**
Quaternary	Grey	Grey Pale yellow	Undecided	Grey
Tertiary	Yellow	Light yellow Pale brown Pale flash Dark yellow Greenish yellow	Undecided	Grey
Cretaceous	Green	Olive green Yellow green Cool green	Green	Green
Jurassic		Blue green	Green	Blue
Triassic		Peacock blue	Violet	Violet & Purple
Permian		Cool blue	Grey	Grey
Pennsylvanian	Blue	Grey	Undecided	Grey
Mississippian		Warm blue		
Devonian	Purple	Blue	Brown	Brown
Silurian		Purple	Greenish Grey	Olive grey
Ordovician		Rose and Pink		Olive green
Cambrian		Red and Coral		Warm brown
Pre-Cambrian	Brown	Yellow brown Brown Bluish grey Brick red	Rose	Pale brown

Colours have also been used to indicate matters such as suitability for construction. For example, in some engineering geological maps, red is used to indicate ground that would require costly foundation, progressing through orange to green to yellow, with the latter as the most favourable ground. This norm has been followed, in some cases/maps as red is used to indicate shear zones.

However, in the current practice some generalized colour codes are in use for practical purposes after developing a consensus amongst experienced geologists. This commonly followed code is given hereunder.

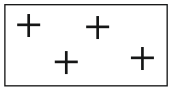
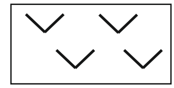
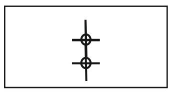
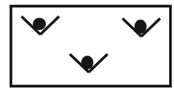
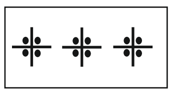
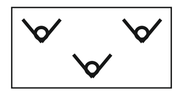
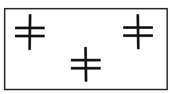
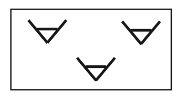
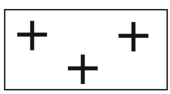
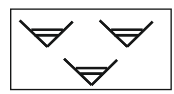
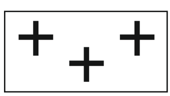
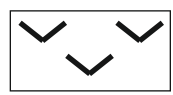
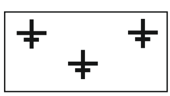
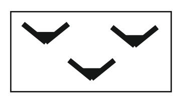
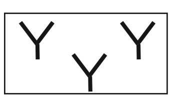
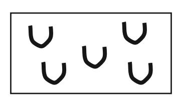
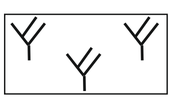
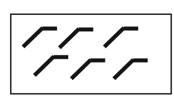
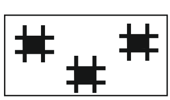
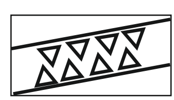
COMMONLY USED COLOUR SCHEME FOR DIFFERENT TYPES OF LITHO UNITS

Overburden (Unconsolidated sand, clay silt, detritus, gravel, breccia, conglomerate etc.)	**RGB** 255,255,102
Igneous rocks of granite clan / Metamorphic Rocks of Granitic composition or texture (Granite, granodiorite, tonalite, rhyolite, dacite, Gneisses, granite gneiss etc.)	**RGB** 192,0,0
Igneous rock syenite clan (Syenite, monzonite, diorite, neheline-synite, trachyte, andesite etc.)	**RGB** 0,134,61
Igneous rock of basic and ultrabasic clan (Gabbro, norite, anorthosite, pyroxenite, peridotite, dunite, dolerite, basalt, lamprophyre, carbonatite, diabase etc.)	**RGB** 81,133,123
Calcareous hard sedimentaries, (Limestone, dolomite etc.)	**RGB** 125,169,223
Non-Calcareous hard sedimentaries, (Sandstone, siltstone, mudstone etc.)	**RGB** 176,135,225
High grade metamorphic rocks	**RGB** 231,149,96
Slate/ phyllite/ low grade schist	**RGB** 95,73,122

Note: The colours suggested above are indicative for use in rock clans in a broad sense. Whenever necessary symbols may be added to differentiate various rock types of one clan.

BASIC SYMBOLS FOR PRINCIPAL TYPES OF IGNEOUS ROCKS

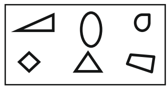
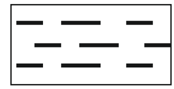
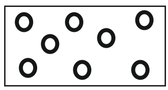
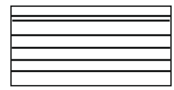
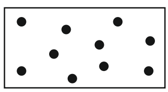
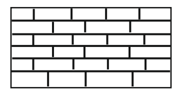
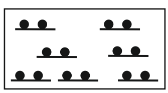
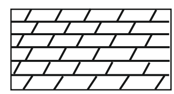
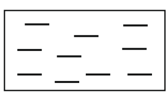
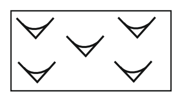
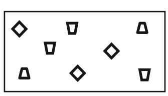
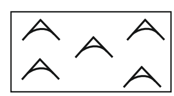
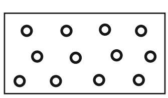
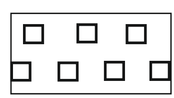
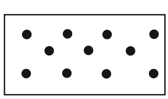
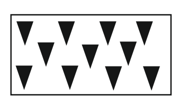
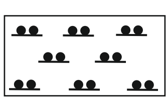
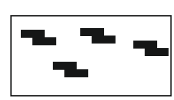
[IS: 7422 (part- 2) 1974, Reaffirmed 2004]

Granite		Rhyolite	
Granodiorite		Dacite	
Quartz diorite		Quartz andesite	
Syenite		Trachyte	
Gabbro		Latite	
Diorite		Andesite	
Norite		Basalt	
Anorthosite		Tuff (Unconsolidated)	
Nepheline Syenite		Pegmatite	
Ultrabasic Rocks		Quartz vein	

Note: There is a great variety of rocks and it is impossible to have an individual symbol for each of the rock types that are found in nature. For this reason the symbols are developed for the most important and frequently occuring rock types. For any characteristic not represented by a symbol, a new symbol may be chosen.

BASIC SYMBOLS FOR PRINCIPAL TYPES OF SEDIMENTARY ROCKS

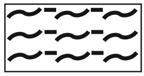
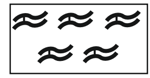
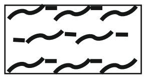
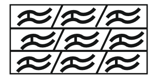
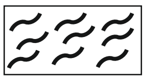
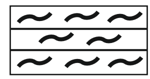
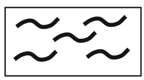
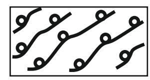
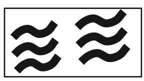
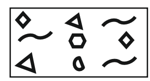
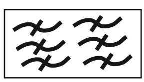
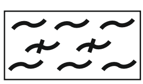
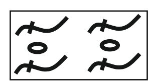
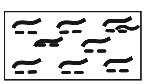
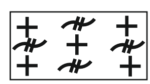
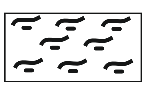
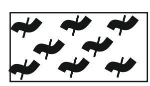
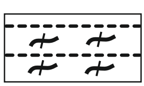
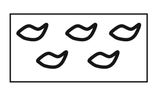
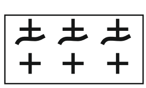
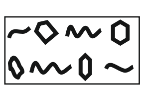
[IS: 7422 (part- 3) 1974, Reaffirmed 2004]

Detritus		Mudstone	
Gravel		Shale	
Sand		Limestone	
Silt		Dolomite	
Clay		Gypsum	
Breccia		Anhydrite	
Conglomerate		Sodium Salt	
Sandstone		Siliceous Rock	
Siltstone		Peat	

Note: There is a great variety of rocks and it is impossible to have an individual symbol for each of the rock types that are found in nature. For this reason the symbols are developed for the most important and frequently occuring rock types. For any characteristic not represented by a symbol, a new symbol may be chosen.

BASIC SYMBOLS FOR PRINCIPAL TYPES OF METAMORPHIC ROCKS

[IS: 7422 (part- 4) 1985, Reaffirmed 2004]

Argillite		Marble	
Slate		Dolomitic marble	
Phyllite		Quartzite	
Schist		Mylonite	
Green Schist (metamorphosed)		Breccia	
Mica Schist		Quartzitic Sandstone	
Streaky gneiss		Augen gneiss	
Quartzitic Schist		Charnockite	
Quartziferous phyllite (Quartzose phyllite)		Amphibolite	
Flaggy quartzite		Migmatite	
Streaky granite		Gneiss	
Khondalite			

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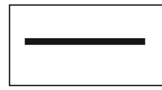
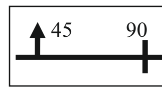
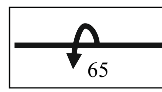
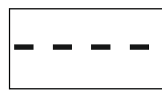
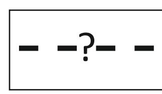
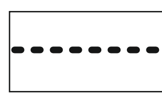
SYMBOLS FOR CONTACTS

[IS: 7422 (PART-5) 1992, Reaffirmed 2012]

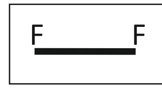
Description	Symbol
Contact	
Contact showing dip, vertical contact with topside known	
Overturned contact, showing dip	
Approximate contact	
Possible contact	
Concealed contact	

SYMBOLS FOR FAULTS

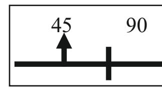
[IS: 7422 (Part-5) 1992, Reaffirmed 2012]

Description **Symbol**

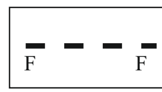
Fault



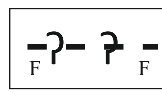
Fault, showing dip



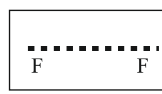
Fault, approximately located



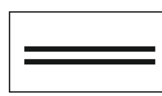
Fault, inferred or doubtful



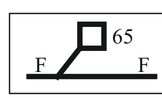
Concealed fault



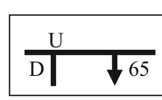
Lineament



Fault (showing bearing and plunge of grooves, striations or slickensides)



Fault, showing dip (U-upthrown side, D-downthrown side)

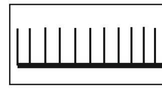


Fault showing relative horizontal movement

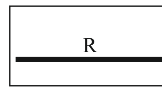
SYMBOLS FOR FAULTS

Fault (showing bearing & plunge of apparently downthrown block)

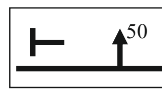
Normal fault (hachures on downthrown side)



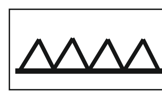
Reverse fault (R, upthrown side)



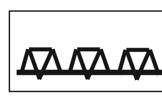
Thrust fault (T, upper plate)



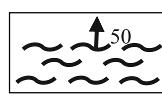
Thrust fault (sawteeth on upper plate, major thrust fault)



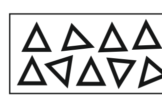
Overturned thrust fault, sawteeth in dip direction, bar on side of tectonically higher plate



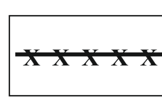
Fault (shear or mylonite) zone showing dip



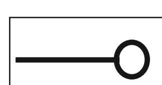
Fault breccia



Fault, intruded by dyke



Termination of fault

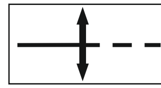


SYMBOLS FOR FOLDS

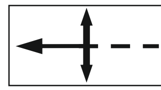
[IS: 7422 (Part-5) 1992, Reaffirmed 2012]

Description — **Symbol**

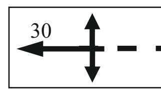
Anticline, showing crestline



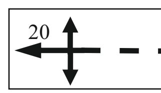
Anticline, showing crestline & direction of plunge



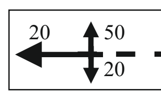
Anticline, shwoing crestline & plunge



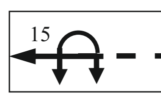
Asymmetric anticline showing crestline & plunge, shorter arrow indicates steeper limb



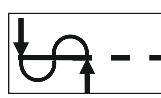
Asymmetric anticline showing dip of limbs and plunge



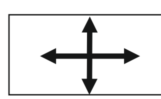
Overturned anticline showing direction of dip of limbs & plunge



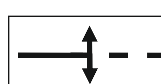
Inverted anticline, Arrows show direction of dip of limbs



Dome

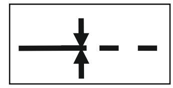


Antiform

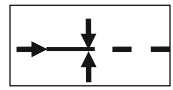


SYMBOLS FOR FOLDS

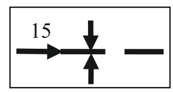
Syncline showing troughline



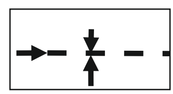
Syncline showing trough line & direction of plunge



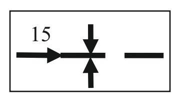
Syncline showing trough line & plunge



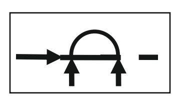
Asymmetric syncline showing trough line and plunge.
Short arrow indicates steeper limb



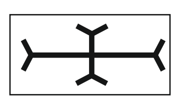
Asymmetric syncline showing dip of limbs and plunge



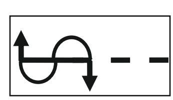
Overturned syncline showing dip of limbs and plunge



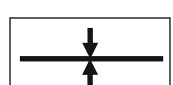
Basin



Inverted syncline, arrow showing direction of dip of limbs

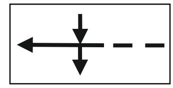


Synform, drawn on foliation, cleavage or bedding

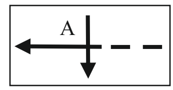


SYMBOLS FOR FOLDS

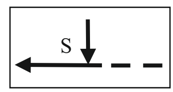
Monoclines showing trace and plunge of axes, dashed where approximately located



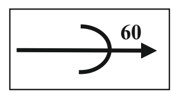
Anticlinal bend showing trace and plunge of axis, dashed where approximately located



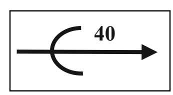
Syncline showing traces and plunge of axis, dashed where approximately located



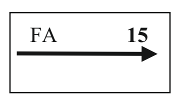
Minor anticline, showing plunge



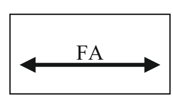
Minor syncline, showing plunge



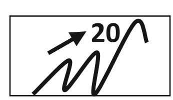
Minor fold axis, showing plunge



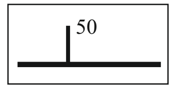
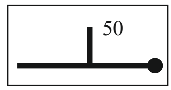
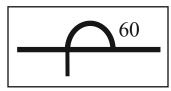
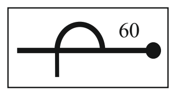
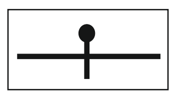
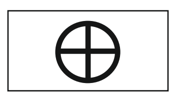
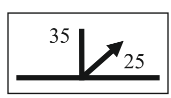
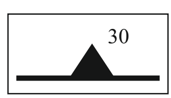
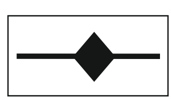
Minor fold axis, horizontal



Minor fold showing plunge of axes

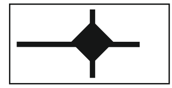


SYMBOLS FOR PLANAR FEATURES
[IS: 7422 (Part-5) 1992, Reaffirmed 2012]

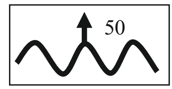
Description	Symbol
Strike and dip of beds	
Strike and dip of beds (Top beds known from sedimentary features, used only in areas of complex structure where overturning is also recognized)	
Strike and dip of overturned beds	
Strike and dip of overturned beds (top of beds known)	
Strike of vertical beds (top of beds known)	
Horizontal beds	
Strike and dip of beds and plunge of slicken-sides	
Strike and dip of foliation	
Strike of vertical foliation (relationship of foliation, orschistocity to bedding not shown in outcrop)	

SYMBOLS FOR PLANAR FEATURES

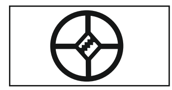
Horizontal foliation



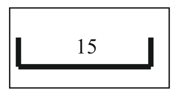
Crumpled, plicated, crenulated or undulatory beds and average dip



Horizontal foliation and bedding



Strike and dip of cleavage

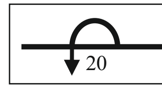


SYMBOLS FOR LINEAR FEATURES

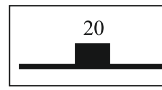
[IS: 7422 (Part-5) 1992, Reaffirmed 2012]

Description **Symbol**

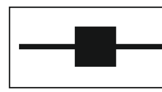
Attitude of overturned beds and parallel foliation



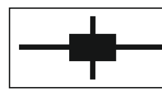
Strike and dip of joints



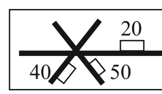
Strike of vertical joints



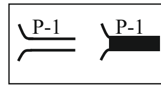
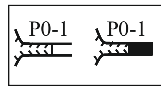
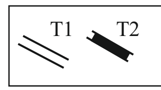
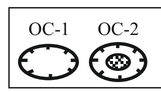
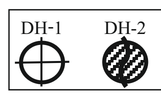
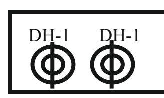
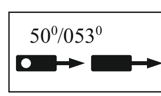
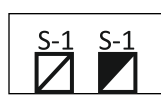
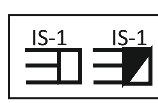
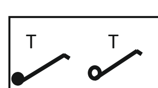
Horizontal joints



Strike and dips of multiple joints

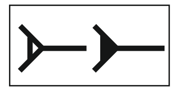
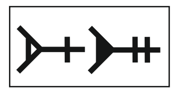
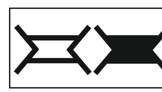
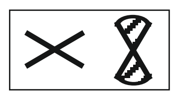


SYMBOLS FOR SURFACE OPENINGS AND EXPLORATION FOR USE IN LARGE SCALE MAPS
[IS: 7422 (Part-5) 1992, Reaffirmed 2012]

Description	Symbol
Portal or slit	
Portal or open cut	
Trench	
Prospect pit or open cut	
Drill hole (upto or including 150mm)	
Drill hole,larger diameter (more than 150mm)	
Drill hole (no geological data available)	
Drill hole inclined (showing bearing and Inclination of surface)	
Vertical shaft	
Inclined shaft	
Thermal spring	

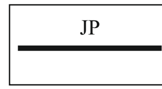
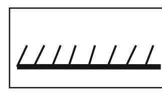
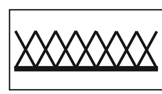
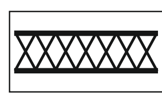
SYMBOLS FOR SURFACE OPENINGS AND EXPLORATION FOR USE IN SMALL SCALE MAPS

[IS: 7422 (Part-5) 1992, Reaffirmed 2012]

Description	Symbol
Portal of tunnel or adit	
Inaccessible tunnel or adit	
Trench	
Prospect pit	

SYMBOLS FOR SLIP PLANES AND MINOR SHEAR SEAMS

[IS: 7422 (Part-5) 1992, Reaffirmed 2012]

Description	Symbol
Joint plane	
Slip plane	
Shear zone 1 to 5cm (Thick crushed rock)	
Shear zone 5 to 15cm (Thick crushed rock)	
Shear zone - thickness defined by border lines	
Glide crack	

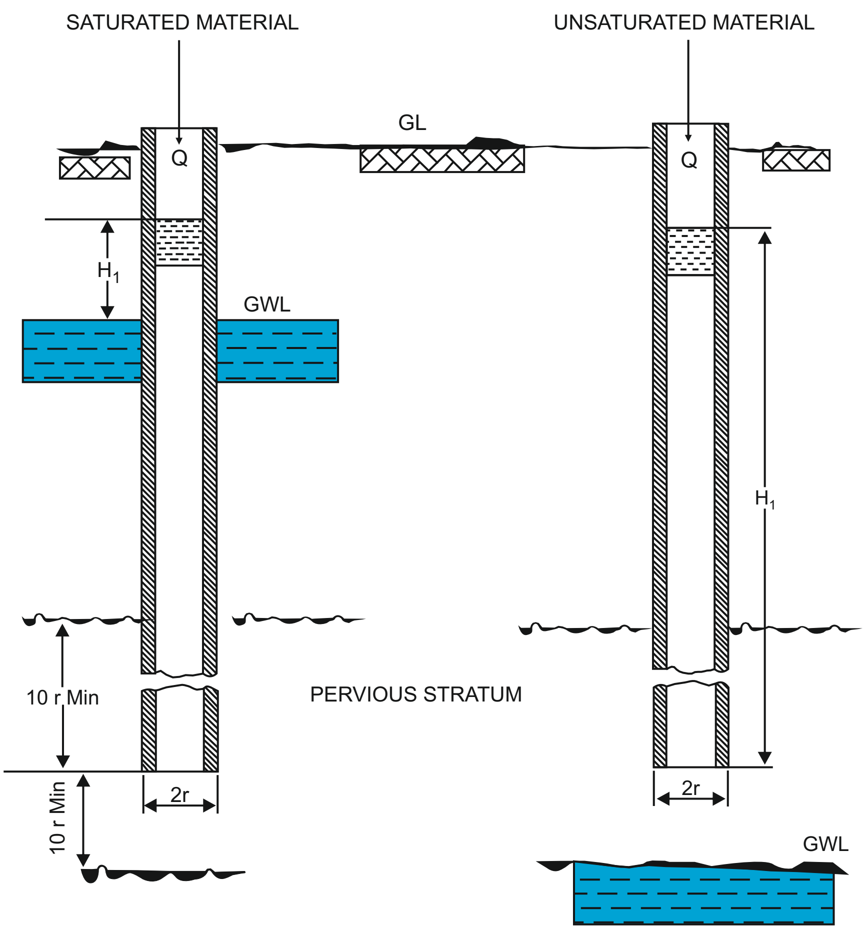
BASIC SOIL COMPONENTS
[IS: 1498- 1970, Reaffirmed 1997]

Sl No.	Soil	Soil Component	Symbol	Particle Size Range & Description
I)	Coarse-grained Components	Boulder	None	Rounded to angular, bulky, hard rock particle; average diameter more than 300 mm
		Cobble	None	Rounded to angular, bulky hard rock particle; average diameter smaller than 300 mm but retained on 75-mm
		Gravel	G	Rounded to angular, bulky, hard rock particle; passing 75-mm IS Sieve but retained on 4.75-mm IS Sieve Coarse: 80-mm to 20-mm IS Sieve Fine : 20-mm to 4.75-mm IS Sieve
		Sand	S	Rounded to angular, bulky, hard rock particle; passing 4.75-mm IS Sieve but retained on 75-micronn IS Sieve Coarse: 4.75-mm to 20-mm IS Sieve Medium: 2.0-mm to 425-micron IS Sieve Fine:425-micron to 75-micron IS Sieve
ii)	Fine-grained Components	Silt	M	Particles smaller than 75-micrn IS Sieve; identified by behaviour, that is, slightly plastic or non-plastic regardless of moisture and exhibits little or no strength when air dried;
		Clay	C	Particles smaller than 75-micrn IS Sieve identified by behaviour, that is, it can be made to exhibit plastic properties within a certain range of moisture and exhibits considerable strength when air dried
		Organic Matter	O	Organic matter in various sizes and stages of decompositition Coarse : 75-micron to 7.5-micron Fine: 7.5-micron to 2-micron

DETERMINATION OF PERMEABILITY IN OVERBURDEN: CONSTANT HEAD METHOD

The Constant head method is used when the permeability of the strata being tested is very high.In this method a hole is drilled or bored up to the level at which the test is to be performed. The casing is simultaneously driven as the drilling or boring of the hole is in progress. After the required level is reached the hole is to be cleaned by means of scooping spoons and bailer. In case of drilling below ground water level, the hole is cleaned by passing air under pressure by air jetting method.

After the hole is cleaned the test is started by allowing clear water through metering system to maintain gravity flow at constant head. The observation of the water level at 5 minutes intervals is to be noted. When three consecutive readings show constant values, further observations may be stopped and the constant reading should be taken to the depth of water level.Co-efficient of permeability 'K' is given by:



K = C_1 x Q/H

K = Co-efficient of permeability in cm/sec

C_1 = Constant, varies with the size of casing and rods, the values are given in the table below

Q = Discharge in l/m

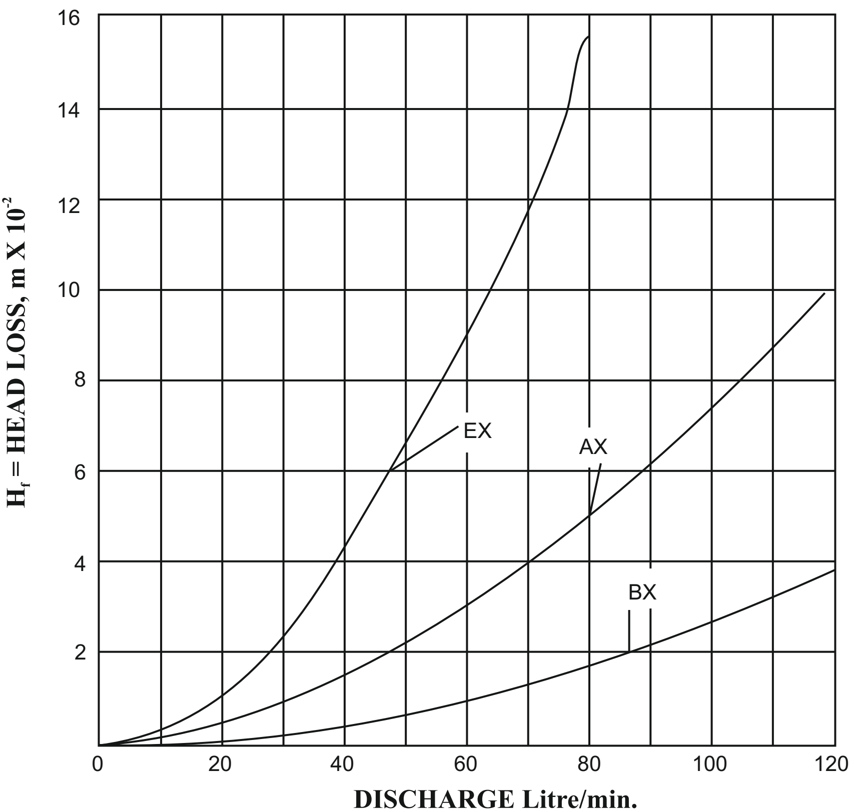


Fig. Head Loss Due to Pipe Friction per 3m Length of Drill Rod versus Discharge

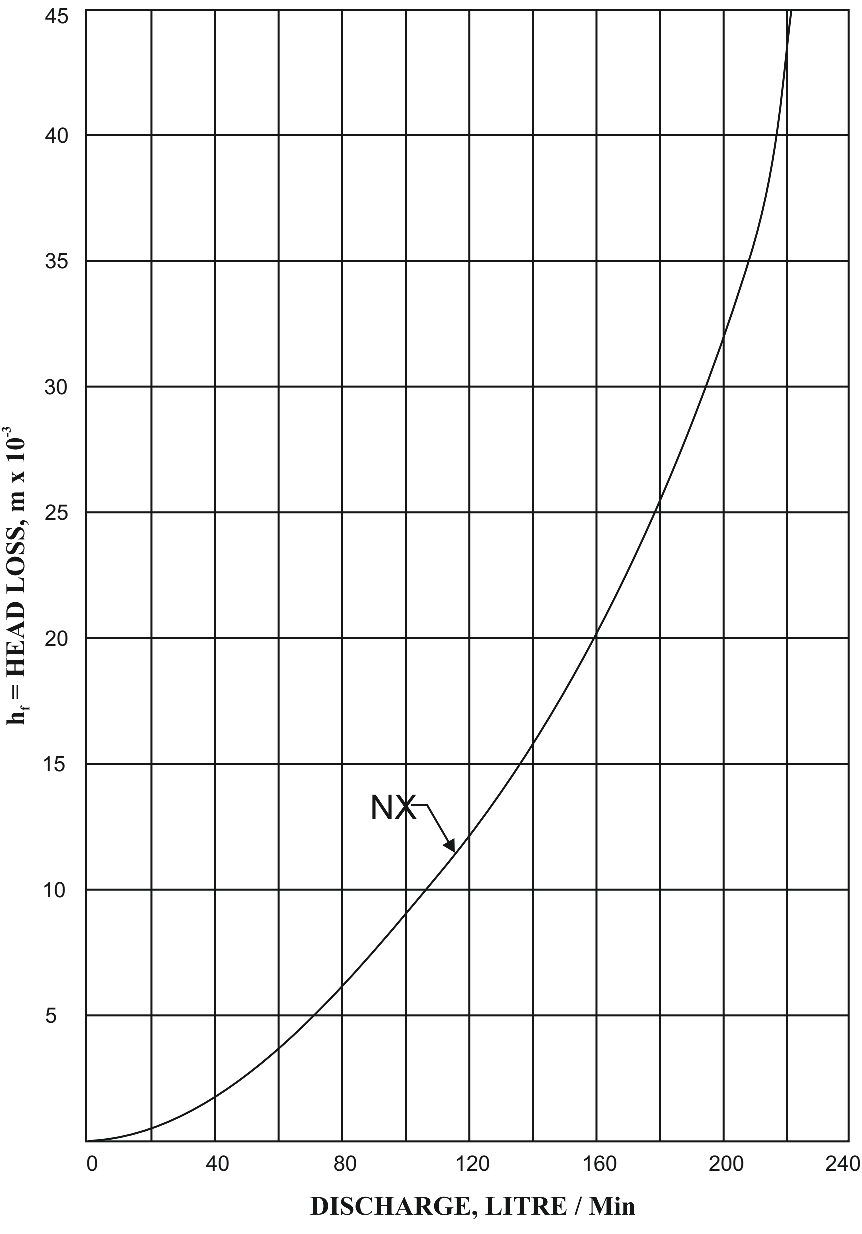


Fig. Head Loss Due Pipe 3m Length of Drill Rod versus Discharge

Formula Used:

$$H_f = \frac{f.\,l}{a} \times \frac{[Q/(\pi d^2/4)]^2}{2g}$$

Where

H_f = Head loss

Q = Discharge

l = Length of rod

d = Inside diameter of Rod

f = Friction constant

g = Acceleration due to gravity

VALUE C_1

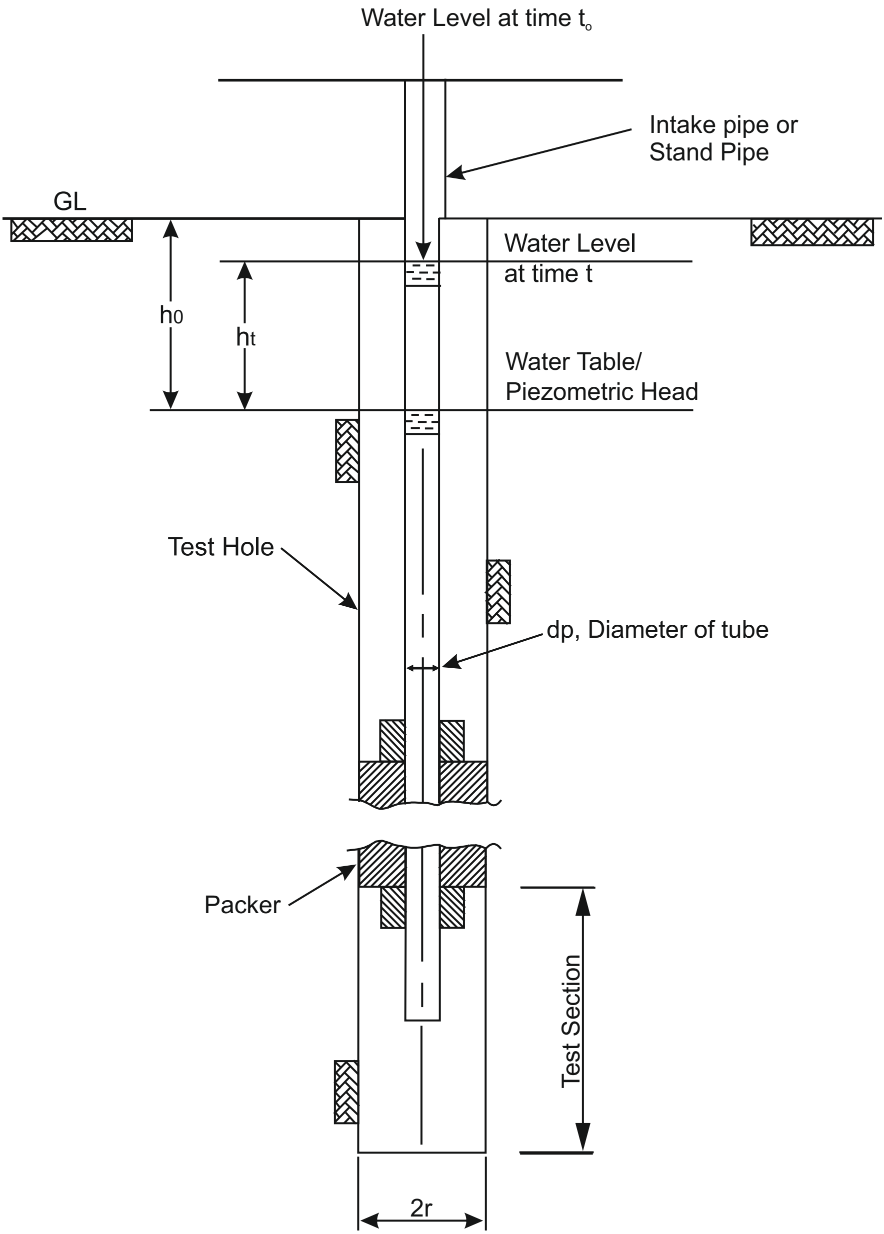
Size of Casing	EX	AX	BX	NX	HX*	PX*	SX*
Diameter of Hole (2r) in mm	38.1	48.4	60.3	76.2	100	150	200
$C_1 \times 10^{-3}$	15.90	12.05	10.0	7.95	6.06	4.04	3.03

* Approximate equivalent size (not given in BIS code).

[IS: 5529 (Part-1) 1985]

DETERMINATION OF PERMEABILITY IN OVERBURDEN: FALLING HEAD METHOD

The falling head method is used when the permeability of the strata being tested is low. The method is more accurate when test conducted below water table.



In this method, a hole is drilled or bored down to the bottom of the test horizon. The hole is cleared either by means of scooping spoons and bailer or by passing air under pressure by air jetting method. After cleaning the hole a packer is to be fixed at the desired depth so as to enable the testing of the full section of the hole below the packer. In conducting packer tests standard drill rods (see IS: 6926:1973) should be used. The water pipe is filled with water up to its top and the rate of fall of the water inside the pipe is recorded. If the hole cannot stand as such then casing pipe with perforated section in the strata to be tested should be used.

Coefficient of Permeability can be calculated as:

$$K = \frac{dp^2}{8L} \log_e \left(\frac{L}{R}\right) \frac{\log_e h_1/h_2}{t_2 - t_1}$$

Where,

K = Co-efficient of permeability

dp = Diameter of tube

L = Length of test section

h1 = Head of water in the stand pipe at time t_1 above piezometeric surface,

h2 = Head of water in the stand pipe at time t_2 above piezometeric surface

R = Radius of hole

(IS: 5529(Part-I, 1985)

Permeability Ranges

Relative permeability	**cm/sec**	**ft/year**	**Typical Soil**
Very permeable	Over 1x 10^{-1}	1,00000	Coarse gravel
Medium	1x10^{-1} to 1 x 10^{-3}	1,00000 to 1000	Sand
Low	1 x 10^{-3} to 1 x 10^{-5}	1000 to 10	Very fine sand Silty Sand Sandstone
Very low	1 x 10^{-5} to 1 x 10^{-7}	<10 to >1	Silts Highly organic Clay
Impervious	Less than 1 x 10^{-7}	>1	Clay Clay shales Intact rocks

1Lugeon= 1 x 10^{-5} cm/sec = 10 ft/year

PERMEABILITY OF SOME TYPICAL ROCKS

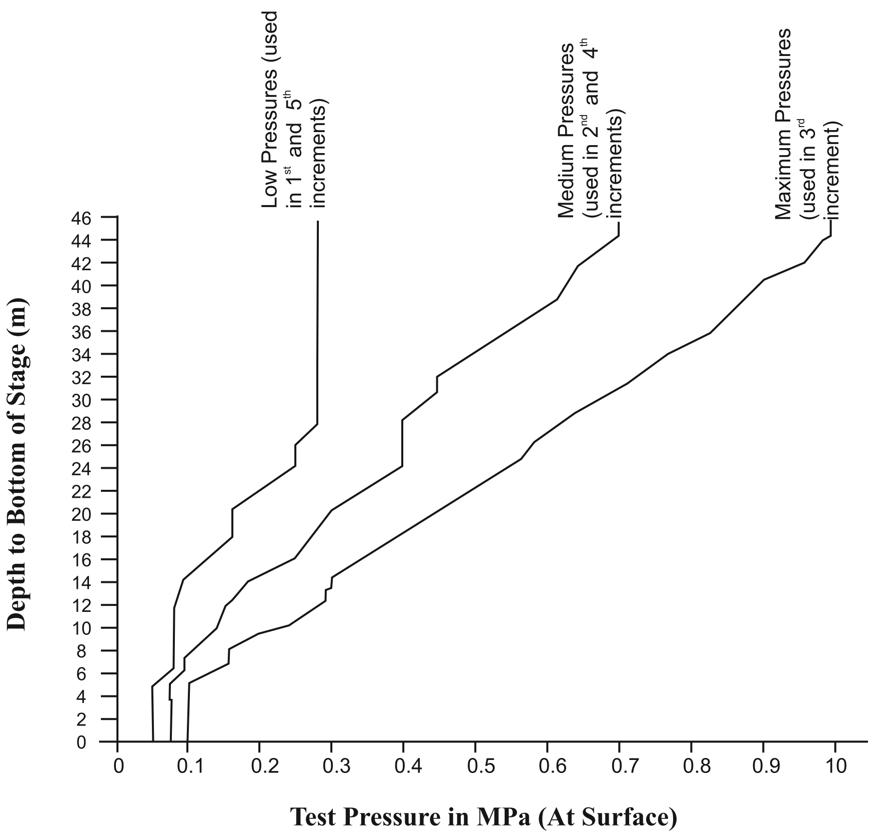
Rocks	**K(cm/s) for Rock With water (20°C) as Permeant**	
	Lab	**Field**
Sandstone	3×10^{-3} to 8×10^{-8}	1×10^{-3} to 3×10^{-8}
Shale	10^{-9} to 5×10^{-13}	10^{-8} to 10^{-11}
Limestone	10^{-5} to 10^{-13}	10^{-3} to 10^{-7}
Basalt	10^{-12}	10^{-2} to 10^{-7}
Granite	10^{-7} to 10^{-11}	10^{-4} to 10^{-9}
Schist	10^{-8}	2×10^{-7}

From Brace (1978), Davis and De Wiest (1966) and Serafim (1968)

HOULSBY'S APPROACH IN INTERPRETATION OF WATER PRESSURE TEST IN BEDROCKS

Water pressure tests are usually carried out in bore holes drilled in order to know the sub-surface geological condition in the investigation stage. The procedure consists of injecting water into the borehole and measuring the amount of water that can be forced into the tested section of the hole within a given time and at a given pressure. Water loss during the test is expressed in terms of lugeons.

Pressures used for the test section are governed either by depth of the stage under test, competency of foundation to withstand the pressure or maximum equivalent of reservoir head. The relationship between depth and allowable pressure for normal rock is shown below.



HOULSBY'S APPROACH AND REPORTING LUGEON VALUE

	Limit of Test Pressure Applied to the Test Zone in MPa per m for rock load
Unconsolidated or poorly consolidated sedimentary formations	0.012
Consolidated horizontally bedded Sedimentary formations	0.018
Hard igneous and metamorphic rocks	0.024

For each stage length, test is done at different pressures for a particular time. Usually five consecutive tests are done each of 5 minutes duration so that:

1. For 5 minutes at low pressure - Pressure "a"
2. For 5 minutes at medium pressure - Pressure "b"
3. For 5 minutes at high pressure - Pressure "c"
4. For 5 minutes at medium pressure - Pressure "b"
5. For 5 minutes at low pressure - Pressure "a"

Generally, the low, medium and high pressures are taken as 50 (0.34MPa), 100 (0.67MPa) and 150 (1.03MPa) psi respectively. Water loss noted at different pressure in terms of onward and return cycle are mathematically calculated in terms of lugeon unit at a standard pressure, so that comparison can be made among all five values. The mathematical relation for calculating the lugeon is given as follows:

$$Lugeon\ value = \frac{\text{Water taken in test } \left(\frac{l}{m}\ minutes\right) x\ 1.0\ MPa}{\text{Test Pressure (MPa)}}$$

Lugeon values calculated at different pressures in onward and return cycle may differ substantially for a single stage length. The choice of the reporting lugeon value is based on the flow condition in the subsurface openings (Houlsby, 1976).

Houlsby (1976) has identified the following groups of physical conditions, which can be interpreted as:-

Group "A" - Laminar flow

Group "B" - Turbulent flow

Group "C" - Dilation

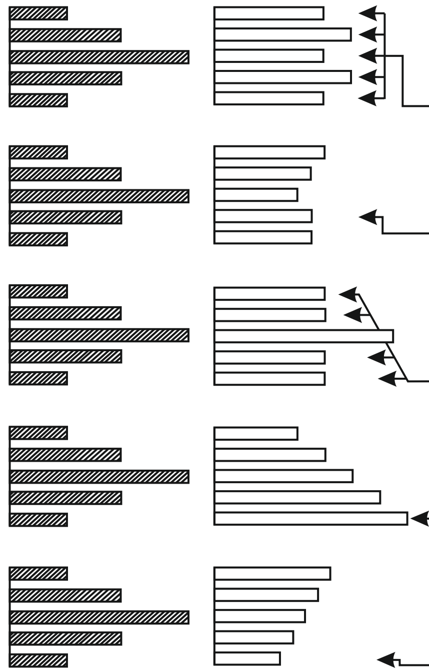
Group "D" - Wash out of joint filling material

Group "E" - Void filling

The lugeon value at each of the five test pressure is plotted in the form of bar charts for a particular depth slab and flow conditions are detected. The table shows how the main groupings and interpretations are done.

INTERPRETTION OF WATER PRESSURE TEST DATA (AFTER HOULSBY,1976)

Test Pressures shown in Appendix Relative magnitude	Lugeon Pattern Lugeons Calculated for each 10 minute run Relative Magnitudes shown in generalized patterns actual magnitude can very widely	Characteristics of the pattern & its interpretation	Which of the Lugeon value in the pattern should used as the reported permeability?
Group A-Laminar flow 1st TEN MINUTE RUN 2nd 3rd 4th 5th		All 5 Lugeons are about equal. Hence laminar flow	Use the average of the five Lageons its the nearest whole number
Group B- Turbulent Flow 1st TEN MINUTE RUN 2nd 3rd 4th 5th		Lowest Lugeon value occurring at highest pressure. Hence turbulent flow.	Use the Lugeon value for the highest pressure.
Group C- Dilation Flow 1st TEN MINUTE RUN 2nd 3rd 4th 5th		Highest Lugeon occurring at highest pressure. Hence dilation.	Use the Lugeon value for the lowest or medium pressure.
Group D- Wash Out 1st TEN MINUTE RUN 2nd 3rd 4th 5th		Lugeons increasing at test proceeds. Hence the test is causing changes to the foundation.	Use the highest Lugeon value unless special reasons require otherwise.
Group E- Void Filling 1st TEN MINUTE RUN 2nd 3rd 4th 5th		Lugeons decreasing at test proceeds. Hence the test is gradully filling extensive voids.	Usually use the final Lugeon value.



WATER PRESSURE TEST (BED ROCK)

Project:

Feature: Date:

Location: Bore hole no:

Coordinate: Depth of Bore Hole (m):

Test Section: depth: fro....m to…….m. Diameter:

Length of Test Section (L): Height of Manometer from ground

Type of Test: Double Packer Test (H1): 1.5m Ground Water Table (H2): 18.3m

Sr. No.	Depth of Packer		P_0 kg/cm^2	P kg/cm^2	t (min)	Q_1	Q lit/min/in	Lugeon	Flow Condition	Reporting Lugeon
	Upper	Lower								
1	35	38	1.5	3.48	15	111	2.46	7.06		
2			3.0	4.98	15	119	2.64	5.31	Turbulant	4.14
									Flow	
3			4.5	6.48	15	121	2.68	4.14		
4			3.0	4.98	15	94	2.08	4.19		
5			1.5	3.48	15	78	1.73	4.98		

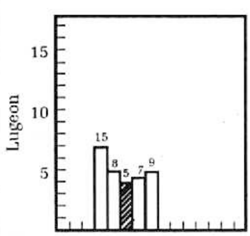
SAMPLE CALCULATION (SATURATED COND.)

Lugeon :- $\dfrac{Q \times 10}{P}$

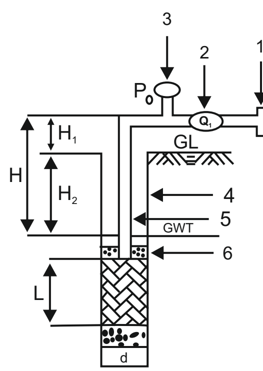
$= \dfrac{2.46 \times 10}{3.48} = 7.06$

Flow Condition : B, Turbulent Flow

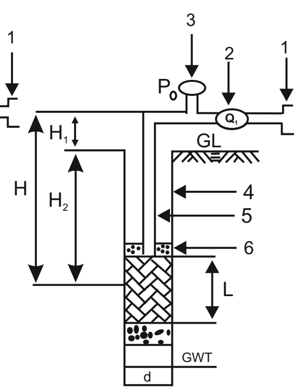
DETERMINATION OF FLOW CONDITION



35 to 38 m
'P' in kg/cm²



SATURATED STRATA



UNSATURATED STRATA

1 Pump
2 Flow Meter
3 Pressure Gauge
4 Drill Hole
5 Injection Pipe
6 Packer

Where

P_0 :- Pressure of Manometer

H_1 :- Height of Pressure Gauge

H_2 :- Depth of Ground Water or above Test Section (Depending upon strata)

P :- Effective Pressure (Pressure at Packer) $P_0 + H_1 + H_2$ in Kg/Cm^2

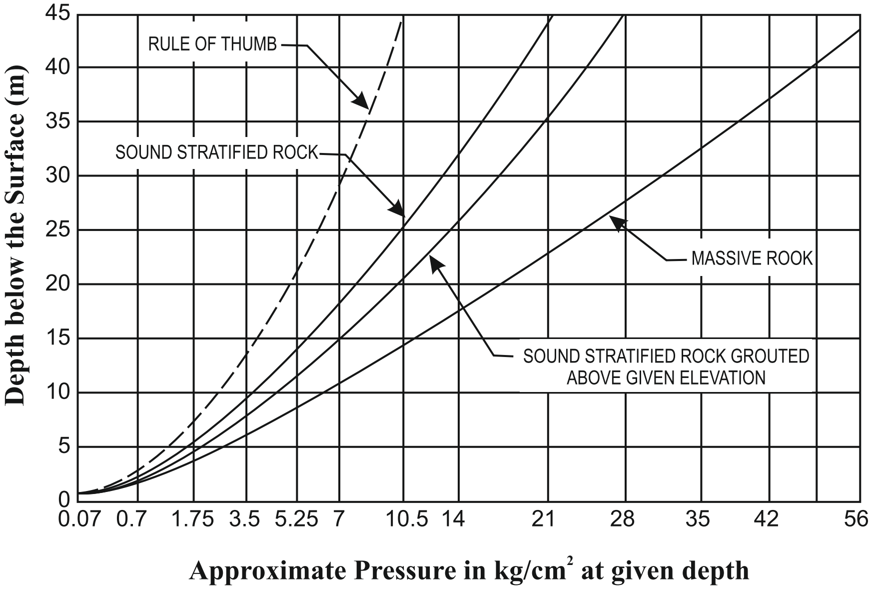
H :- $H_1 + H_2$ converted into Kg/cm^2

t :- Injection Time

Q1 :- Water Intake during Time

Q :- Water Intake/minute/meter

GUIDE FOR GROUTING PRESSURE



IS : 6066 - 1994

ROCKMASS CLASSIFICATION APPLICABLE IN ENGINEERING PROJECTS

Rock Mass Characterization in Engineering Geological Mapping

Engineering Geological Map portrays the basic geology incorporating the lithology, the structure and the cover characteristics. Detailed geotechnical evaluation by proper application of the rock mass classification approach requires careful study on maximum possible exposures/outcrops of the area.

The finer details of rockmass characteristics and discontinuity parameters of an outcrop are recorded on data sheet for assessing rock mass conditions. The joint or discontinuity is described by its spatial orientation, spacing, persistence, aperture, filling, roughness and alteration. Rock mass description includes the rock type, strength of the intact rock mass, degree of weathering, geological structure, stress reduction factor and volumetric count of joints apart from the hydrogeological condition. All the rock quality parameters are recorded on documentation data sheets.

List of Abbreviations for Rock Quality Parameters

Table 1 : Length and Direction (Persistence)

L/DD	L= discontinuity length along dip direction
L/SD	L= discontinuity length along strike direction

Table 2 : Type of Termination

x	Discontinuities which extend outside the exposure
r	Visibly terminate in rock exposure
d	Terminate against other discontinuities in exposure

Table 3 : Persistence

Very Low	=	< 1 m
Low	=	1-3 m
Medium	=	3-10 m
High	=	10-20 m
Very High	=	>20 m

IS: 11315 (Part-3) 1987

Table 4 : Spacing

Very closely spaced	=	< 6 cm
Closely Spaced	=	6 – 20 cm
Mod. Spaced	=	20-60 cm
Widely Spaced	=	60-200 cm
Very widely spaced	=	>200 cm

IS: 11315 (Part-2) 1987

Table 5 : Aperture	**Description**	
< 0.25 mm	Tight	"Closed" feature
0.25-0.5 mm	Partly open	
0.5-2.5 mm	Open	"Gapped" feature
2.5-10 mm	Moderately wide	
> 10 mm	Wide	
1-10 cm	Very wide	"Open" feature
10-100 cm	Extremely wide	
>1 m	Cavernous	

IS: 11315 (Part-6) 1987

Table 6 : Roughness

a) Small scale (several centimeters) &
b) Intermediate scale (several meters)

i) Rough (or irregular), stepped
ii) Smooth, stepped.
iii) Slickensided stepped.
iv) Rough (or irregular) planar
v) Smooth undulating
vi) Slickensided, undulating.
vii) Rough (or irregular) planar
viii) Smooth, planar
ix) Slickensided, planar

IS: 11315 (Part-6) 1987

Table 7 : Type of Filling	
SC	Swelling clay
IC	Inactive Clay
C	Chlorite
T	Talc
G	Graphite
CR	Crushed rock fragments of sand-like gouge
PFC	Porous of flaky calcite, gypsum.

Table 8 : Strength

Grade	Description	Field Identification	App. UCS (MPa)
R0	Extremely weak rock	Indented by thumb nail.	0.25-1.0
R1	Very Weak rock	Crumbles under firm blow with point of geological hammer, can be peeled by a pocket knife.	1-5
R2	Weak rock	Can be peeled by a pocket knife with difficulty. Shallow indentation made by firm blow with point of geological hammer.	5-25
R3	Medium strong rock	Cannot be scraped or peeled with a pocketknife, specimen can be fractured with single firm blow or geological hammer.	25-50
R4	Strong rock	Specimen requires more than one blow of geological hammer to fracture it.	50-100
R5	Very strong rock	Specimen requires more than one blow of geological hammer to fracture it.	100-250
R6	Extremely strong rock	Specimen can only be chipped with geological hammer.	>250

IS: 11315, Part-5- (1987)

Table 9 : Geological Structure	
M	Massive
SJ	Slightly jointed
MJ	Moderately jointed.
IJ	Intensively jointed
SFA	Slightly faulted
MFA	Moderately faulted.
IFA	Intensively faulted.
SFO	Slightly folded.
MFO	Moderately folded.
IFO	Intensively folded.

Table 10 : Water Inflow (per 10m tunnel length)	
CD	Completely Dry - Inflow Nil
DP	Damp - < 10 l/min
W	Wet - 10-25 l/rnin
DR	Dripping - 25-125 l/min
F	Flowing - > 125 l/m in

Table 11 : Block Description (Shape)		
M	Massive	Few joints or very wide spacing
B	Blocky	Approximately equidimensional
T	Tabular	One dimension considerably smaller than the other two
CO	Columnar	One dimension considerably larger than the other two
I	Irregular	Wide variations of block size and shape
Cr.	Crushed	Heavily jointed or "Sugar cube"

IS:11315 [Part -10) 1987

Table 12 : Block Dimension/Block size	
Description	Jv (Joints /m3)
Very large blocks	< 1.0
Large blocks	1-3
Medium sized blocks	3-10
Small blocks	10-30
Very small block	>30
Crushed rock, typically a clay free crushed zone	>60

IS:11315 (Part-10) 1987

टीएचडीसी इंडिया लिमिटेड
THDC INDIA LIMITED

DATASHEET FOR ROCK QUALITY PARAMETERS

PROJECT					LOCATION		
Outcrop No.							
Type of joint							
Joint set Number							
Dip amount							
Dip Direction							
Joint Description	Length/Direction						
	Type of Termination						
	Persistence (m)						
	Spacing (cm)						
	Aperture (mm)						
	Roughness						
	Alteration						
	Type of Filling						
Rock Mass Description	Rock Type						
	Strength						
	No. of Joint sets						
	Degree of Weathering						
	Geological Structure						
	Water Seepage						
	SRF						
	Block Description						
	Block Size	Block Dimension					
		No. of Joints/m3					
Remarks							
Date:							**GEOLOGIST**

CSIR (RMR) SYSTEM OF ROCKMASS CLASSIFICATION

Bieniawski,(1973) proposed the RMR (Rock Mass Rating) system also known as "Geomechanics classification" for jointed rock masses. The five basic parameters considered for this classification are

(i) Strength of rock,

(ii) RQD,

(iii) Spacing of joints/discontinuities

(iv) Condition of joints and

(v) Ground water conditions.

A rating is allocated to each parameter and the overall rating for the rock mass is arrived at by adding the rating for each parameter (Table). This overall rating is adjusted for accounting the effect of joints orientations by applying correction to estimate the final RMR value which is related to five classes of rock mass as described below :-

RMR	ROCK CLASS
100-81	Very good
80-61	Good
60-41	Fair
40-21	Poor
<21	Very Poor

GEOMECHINCS CLASSIFICATION OF JOINTED ROCK MASS (After Bieniawski, 1989)

A. CLASSIFICATION PARAMETER AND THEIR RATINGS									
	Parameter		Range of values						
1	Strength of intact rock material	Point load strength index	>10Mpa	4-10 Mpa	2-4 Mpa	1-2 Mpa	For this low range UCS test is preferred		
		Uniaxial Compressive strength	>250Mpa (extremely strong)	100-250 Mpa (very strong)	50-100 Mpa (strong)	25-50Mpa (medium strong)	5-25Mpa (weak)	1-5Mpa (very weak)	<1Mpa
	Rating		15	12	7	4	2	1	0
2	RQD		90%-100%	75%-90%	50%-75%	25%-50%	<25%		
	Rating		20	17	13	8	3		
3	Spacing of discontinuity		>2m	0.6-2m	200-600 mm	60-200mm	<60mm		
	Rating		20	15	10	8	5		
4	Condition of discontinuities		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation <1mm Slightly weathered walls	Slightly rough surfaces Separation <1mm Highly weathered walls	Slickensided surfaces or Gouge<5mm thick or Separation1-5 mm continuous	Soft gouge>5mm thick or Separation>5mm Continuous		
	Rating		30	25	20	10	0		
5	Ground Water	Inflow per 10m tunnel length (l/m)	None	<10	10-25	25-125	>125		
		Joint water press/ Major principals	0	<0.1	0.1-0.2	0.2-0.5	>0.5		
		General condition	Completely dry	Damp	Wet	Dripping	Flowing		
		Rating	15	10	7	4	0		

GEOMECHINCS CLASSIFICATION OF JOINTED ROCK MASS (After Bieniawski, 1989)

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS					
Strike and dip orientation	Very favourable	favourable	Fair	Unfavourable	Very unfavourable
Rating	Tunnel and mines	0	-2	-5	-10-12
	Foundations	0	-2	-7	-15-25
	Slopes	0	-5	-25	-50
C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS					
Rating	100-81	80-61	60-41	40-21	<21
Class number	I	II	III	IV	V
Description	Very good	Good	Fair	Poor	Very poor
D. MEANING OF ROCK CLASSES					
Class number	I	II	III	IV	V
Average stand-up time	20 yrs for 15m span	1 yrs for 10m span	1 week for 5m span	10 hrs for 2.5m span	30 min for 1m span
Cohesion of rock mass (kPa)	>400	300-400	200-300	100-200	<100
Friction angle of rock mass (deg)	>45	35-45	25-35	15-25	<15
E. CLASSIFICATION OF DISCONTINUITY					
Discontinuity length (persistence)	<1m	1-3m	3-10m	10-20m	>20m
Rating	6	4	2	1	0
Separation (Aperture)	None	<0.1mm	0.1-1.0mm	1-5mm	>5mm
Rating	6	5	4	1	0
Roughness	Very rough	Rough	Slightly rough	Smooth	Slicken side
Rating	6	5	3	1	0
Infilling (Gouge)	None	Hard Filling<5mm	Hard filling>5mm	Soft filling<5mm	Soft filling>5mm
Rating	6	4	2	2	0
Weathering	Unweathered	Slightly weathered	Moderately weathered	Highly Weathered	Decomposed
Rating	6	5	3	1	0

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELING			
Strike perpendicular to tunnel axis	Strike parallel to tunnel axis		
Drive with dip- Dip 45°-90°	Drive with dip-Dip 20°-45°	Dip 45°-90°	Dip 20°-45°
Very favourable	Favourable	Very unfavourable	Fair
Drive against dip-Dip 45°-90°	Drive against dip-Dip 20°-45°	Dip 0°-20°- Irrespective of strike	
Fair	Unfavourable	Fair	

ASSESSMENT OF JOINT ORIENTATION FAVOURABILITY FOR STABILITY OF RAFT FOUNDATION

Dip				
0°-10°	10°-30°		30°-60°	60°-90°
	Dip Direction			
	Upstream	Downstream		
Very Favourable	Unfavourable	Fair	Favourable	Very Unfavourable

WEATHERING GRADES OF ROCK MASS
[IS: 4464, 1985 (Reaffirmed 2004)]

Grade (As per IS)	Term	Description	Weathering grade (ISRM)	Material weathering
I	**Fresh**	No visible sign of material weathering, perhaps slight discoloration on major discontinuity surface.	W_1	0%
II	Slightly weathered	Discoloration indicates weathering of rock on major discontinuity surfaces. All the rock material may b0e discoloured by weathering and may be somewhat weaker externally that in its fresh condition.	W_2	< 25%
III	Moderately weathered	Less than half the rock material is decomposed to a soil. Fresh or discoloured rock is present either as a discontinuous framework or as core stones.	W_3	25%- 50%
IV	Highly weathered	More than half of the rock material is decomposed and/ or disintegrated to soil. Fresh or discoloured rock is present either as a discontinuous framework or as core stones.	W_4	50% - 75%
V	Completely weathered	All rock material is decomposed and/or disintegrated to a soil. The original mass structure is still largely intact.	W_5	>75%
VI	Residual Soil	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume, but the soil has not been significantly transported. Large change in volume but soil has not been significantly transported		100%

GUIDE FOR EXCAVATION AND SUPPORT IN ROCK TUNNELS

Geomechanics classification guide for excavation and support in rock tunnels shape horse shoe, width 10m; vertical stress below 25MPa; Construction-Drilling & Blasting

Rock mass class	Excavation	Support Rockbolts (20mm dia. Fully bonded)	Shotcrete	Steel sets
Very good rock I RMR 81-100	Full face, 3m advance	Generally no support required except for occasional spot bolting		
Good rock II RMR 61-80	Full face, 1,0-1.5m advance Complete support 20m from face	Locally, bolts in crown, 3m long spaced 2.5m with occasional mesh.	50mm in crown where required	None
Fair rock III RMR 41-60	Top heading and bench, 1.5-3m advance in heading. Commence support after each blast. Complete support 10m from face.	Systematic bolts 4m long, spaced 1.5-2m in crown and walls with wire mesh in crown.	50-100mm in crown, 300mm in side walls.	None
Poor rock IV RMR 21-40	Top heading and bench, 1-1.5m advance in heading. Install support concurrently 10m from face.	Systematic bolts 4-5m long, spaced 1-1.5m in crown and walls with wire mesh.	100-150mm in crown, 100mm on sides	Light ribs spaced 0.75m where required
Very poor rock V RMR <20	Multiple drifts. 0.5-1.5m advance in top heading. Install support concurrently with excavation. Shotcrete as soon as possible after blasting	Systematic bolts 5-6m long, spaced 1-1.5m in crown and walls with wire mesh. Bolt invert	150-200mm in crown, 150mm on sides and 50mm on face.	Medium to heavy ribs spaced 0.75m with steel lagging and forepoling if required. Close invert

NGI (Q) SYSTEM OF ROCKMASS CLASSIFICATION

Barton et. al. (1974) proposed Q-system of rockmass classification. The rock quality Q is determined by estimating six parameters, viz.,(i) RQD, (ii) Joint set number, Jn , (iii) Joint roughness number, Jr ,(iv) Joint alteration number, Ja,, (v)

$$Q = \frac{RQD}{Jn} \times \frac{Jr}{Ja} \times \frac{Jw}{SRF}$$

Stress reduction factor, SRF and (vi) Joint water pressure, Jw. The numerical value of Q is computed from the following relation:-

The numerical value Q ranges from 0.001 (for exceptionally poor quality squeezing ground) to 1000 (for exceptionally good quality rock which is practically unjointed). This range of Q-value is divided into 9 categories of rock quality as given below:-

Q- VALUE	ROCK QUALITY
0.001-0.01	Exceptionally poor
0.01-0.1	Extremely poor
0.1-1	Very poor
1-4	Poor
4-10	Fair
10-40	Good
40-100	Very good
100-400	Extremely good
400-1000	Exceptionally good

Q- PARAMETER RATINGS FOR USE WITH SUPPORT CATEGORIES

1.	**Rock Quality Designation**	**RQD %**
A	Very poor	0-25
B	Poor	25-50
C	Fair	50-75
D	Good	75-90
E	Excellent	90-100
Note:-	Where RQD is reported or measured as =10 (including 0), a nominal value 10 is used to evaluate Q. -RQD intervals of 5 i.e. 100,95,90 etc. are sufficiently accurate	

2.	**Joint Set Number**	**J_n**
A	Massive, no or few joints	0.5-1.0
B	One joint set	2
C	One joint set plus random joints	3
D	Two joint sets	4
E	Two joint set plus random joints	6
F	Three joint sets	9
G	Three joint set plus random joints	12
H	Four or more joint set, random , heavily jointed, “Sugar Cube”, etc.	15
I	Crushed rock earth like	20
Note:	i) For intersections, use (3.0 x Jn) ii) For portals, use 2.0 x Jn	

3.	**Joint roughness Number**	**J_r**
a) Rock-wall contact, and b) Rock-wall contact before 10cm shear		
A	Discontinuous Joints	4
B	Rough or irregular, undulating	3
C	Smooth, undulating	2
D	Slickenside, undulating	1.5
E	Rough or irregular, planar	1.5
F	Smooth, planar	1.0
G	Slickenside, planar	0.5
Note: Description refer to small scale features and intermediate scale feature, in the order		

b) No rock wall-contact when sheared		
H	Zone containing clay minerals thick enough to prevent rock-wall contact	1.0
J	Sandy, gravelly or crushed zone thick enough to prevent rock-wall contact	1.0
Note:	(i) Add 1.0 if the mean spacing of the relevant joint set is greater than 3m (ii) Jr= 0.5 can be used for planar Slickensided joints having lineation, provided the lineations are oriented for minimum strength	

4.	**Joint Alteration Number**	**F_a**	**J_a**
a) Rock wall contact (No mineral fillings, only coatings)			
A	Tightly healed, hard, non-softening, impermeable filling, i.e. quartz or epidote	-	0.75
B	Unaltered joint walls, surface staining only	25-35°	1.0
C	Slightly altered joint walls. Non-softening mineral coatings, sandy particles, clay free disintegrated rock etc.	25-30°	2.0
D	Silty or sandy clay coatings, small clay fraction (non-softening)	20-25°	3.0
E	Softening or low friction clay mineral coatings, i.e. Kaolinite or mica. Also chlorite, talc, gypsum, graphite etc. and small quantities of swelling clays.	8-16°	4.0
b)	Rock wall contact before 10cm shear (thin mineral fillings)		
F	Sandy particles, clay free disintegrated rock etc.	25-30°	4.0
G	Strongly over-consolidated, non softening, clay mineral fillings (Continuous, but <5mm thickness)	16-24°	6.0
H	Medium or low over –consolidation softening, clay mineral fillings (continuous, but <5mm thickness)	12-16°	8.0
J	Swelling-clay fillings, i.e. montmorillonite (continuous, but <5mm thickness). Value of Ja depends on percent of swelling clay-size particles, and access to water etc.	6-12°	8-12
KLM	Zones or bands of disintegrated or crushed rock and clay (see G,H,J for description of clay condition)	6-24°	6,8 or 8-12
N	Zones or bands of silty or bands of silty clay, small clay fraction (non-softening)	-	5.0
OPR	Thick, continuous zones or bands of clay (see G,H,J for description of clay condition	- 0	10-13 or 6-24

5.	**Joint water reduction factor**	**Water pressure (Kg/cm^2)**	**J_w**
A	Dry excavations or minor inflow, i.e. <5 l/min locally	<1	1.0
B	Medium inflow or pressure, occasional outwash of joints fillings	1-2.5	0.66
C	Large inflow or high pressure in competent rock with unfilled joints	2.5-10	0.5
D	Large inflow or high pressure, considerable outwash of joint fillings	2.5-10	0.33
E	Exceptionally high inflow or water pressure at blasting, decaying with time	>10	0.2-0.1
F	Exceptionally high inflow or water pressure continuing without noticeable decay	>10	0.1-0.05
	Note: (i) Factors C to F are crude estimates. Increase J_w if drainage measures are installed (ii) Special problems caused by ice formation are not considered		

Note: SRF various rock conditions have been indicated elsewhere.

Table 6: Stress Reduction Factor (For underground excavation)		
a)	**Weakness zones intersecting excavation, which may cause loosening of rock mass when tunnel is excavated**	**SRF**
A	Multiple occurrences of weakness zones containing clay of chemically disintegrated rock very loose surrounding rock (any depth)	10
B	Single weakness zones containing clay or chemically disintegrated rock (depth of excavation <50 m)	5
C	Single weakness zones containing clay or chemically disintegrated rock (depth of excavation >50 m)	2.5
D	Multiple shear zones competent rock (clay-free), loose surrounding rock (any depth)	7.5
E	Single shear zones competent rock (clay-free), loose surrounding rock (depth of excavation <50m)	5.0
F	Single shear zones competent rock (clay-free), loose surrounding rock (depth of excavation >50m)	2.5
G	Loose, open joints, heavily jointed or "sugar cube' etc. (any depth)	5.0

Note: i) Reduce these values of SRF by 25-50% if the relevant shear zones only influence but do not intersect the excavation.

b)	**Competent rock, rock stress problems**	**σc/ σ1**	**σt/ σ1**	**SRF**
H	Low stress, near surface	>200	>13	2.5
J	Medium stress, favourable stress	200-10	13-0.66	1.0
K	High stress, very light structure. Usually favourable to stability, may be unfavourable for wall stability	10-5	0.66-0.33	0.5-2.0
L	Mild rock burst (massive rock)	5-2.5	0.33-0.16	5-10
M	Heavy rock burst (strain-burst) and immediate dynamic deformation in massive rock.	<2.5	<0.16	10-20

Note:

I) For strongly anisotropic virgin stress field (if measured): when $5 \leq \sigma_1/\sigma_3 \leq 10$, reduce σ_c to $0.8\sigma_c$ and σ_t to $0.8\sigma_t$. When $\sigma_1/\sigma_3 > 10$ reduce σ_c and σ_t to $0.6\sigma_c$ and $0.6\sigma_t$ where σ_c= unconfined compression strength, and σ_t= tensile strength (point load) and σ_1 and σ_3 are the major & minor principle stresses and σ_t is maximum tangential stress (estimated from elastic theory) .

ii) Few case records available where depth of crown below surface is less than span width. Suggest SRF increase from 2.5 to 5 for such cases (see H).

c)	**Squeezing rock, plastic flow of incompetent rock under the influence of high rock pressure**	**sf/sc**	**SRF**
N	Mild squeezing rock pressure	1.5	5-10
O	Heavy squeezing rock pressure	>5	10-20
d)	**Swelling rock, Chemical swelling activity depending on presence of water**	**SRF**	
P	Mild squeezing rock pressure	5-10	
R	Heavy squeezing rock pressure	10-15	

TUNNELING QUALITY INDEX, 'Q' AND ESTIMATED SUPPORT CATEGORIES

Barton et al. (1974) defined a parameter called Equivalent Dimension (De) of the excavation in relating the value of the index Q to the stability and support requirements of underground excavations:

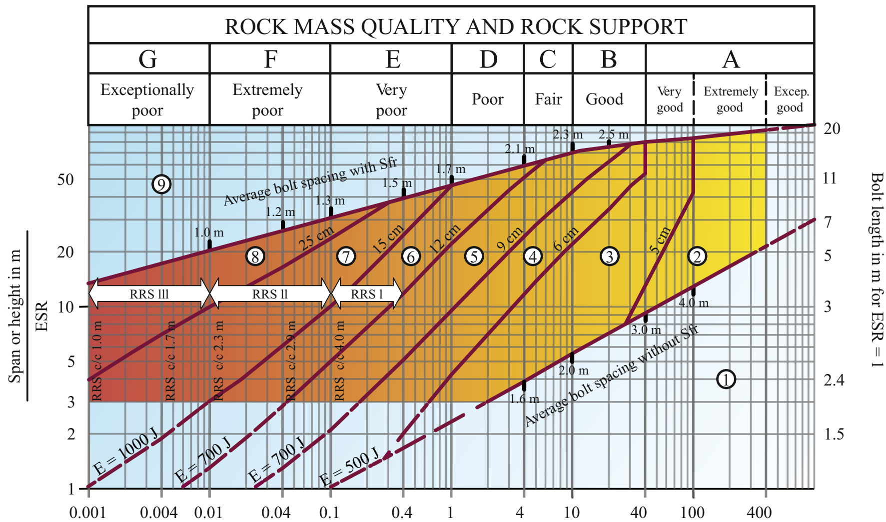
Equivalent Dimension, De is obtained by:-

$$D_e = \frac{\text{Excavation span, diameter or height (M)}}{\text{Excavation support ration, ESR}}$$

The value of ESR is related to the intended use of the excavation and to the degree of security which is demanded of the support system installed to maintain the stability of the excavation. Barton et al (1974) suggest the following values:-

Excavation category		**ESR**
A.	Temporary mine openings	3-5
B.	Vertical Shafts:	
	Circular Section	2.5
	Rectangular / Square Section	2.0
C.	Permanent mine openings, water tunnels for hydropower (Excluding high pressure penstock), Pilot tunnels, drifts, and heading for large excavations	1.6
D.	Storage caverns, water treatment plants minor highway and rail road tunnels, surge chambers access tunnels	1.3
E.	Power stations, major highway or railroad tunnels, civildefence chambers, portals, intersections	1.0
F.	Underground nuclear power stations, railroad stations, factories	0.8

The equivalent dimension, De, plotted against the value of Q is used to define a number of support categories. The updated chart (Grimstad and Barton, 1993) of this is reproduced as under:



Rock mass quality $Q = \frac{RQD}{J} x \frac{J_r}{J_n} \frac{J_w}{SRF_a}$

Support categories

1. Unsupported or spot bolting
2. Spot bolting, **SB**
3. Systematic bolting, bre reinforced sprayed concrete, 5-6 cm, **B+Sfr**
4. Fibre reinforced sprayed concrete and bolting, 6-9 cm, **Sfr (E500)+B**
5. Fibre reinforced sprayed concrete and bolting, 9-12 cm, **Sfr (E700)+B**
6. Fibre reinforced sprayed concrete and bolting, 12-15 cm + reinforced ribs of sprayed concrete and bolting, **Sfr (E700)+RRS I +B**
7. Fibre reinforced sprayed concrete >15 cm + reinforced ribs of sprayed concrete and bolting, **Sfr (E1000)+RRS II+B**
8. Cast concrete lining, **CCA** or **Sfr (E1000)+RRS III+B**
9. Special evaluation

Bolts spacing is mainly based on Ø20 mm

E = Energy absorbtion in bre reinforced sprayed concrete

ESR = Excavation Support Ratio

Areas with dashed lines have no empirical data

RRS - spacing related to Q-value

I
Si30/6 Ø16 - Ø20 (span 10m)
D40/6+2 Ø16-20 (span 20m)

II
Si35/6 Ø16-20 (span 5m)
D45/6+2 Ø16-20 (span 10m)
D55/6+4 Ø20 (span 20m)

III
D40/6+4 Ø16-20 (span 5 m)
D55/6+4 Ø20 (span 10 m)
Special evaluation (span 20 m)

Si30/6 = Single layer of 6 rebars, 30 cm thickness of sprayed concrete

D = Double layer of rebars

Ø16 = Rebar diameter is 16 mm

c/c = RSS spacing, centre - centre

Since the introduction of the system in 1974, two revisions of the support chart have been carried out and published in conference proceedings. An extensive updating in 1993 was based on 1050 examples mainly from Norwegian underground excavations (Grimstad and Barton, 1993). In 2002, an updating was made based on more than 900 new examples from underground excavations in Norway, Switzerland and India. This update also included analytical research with respect to the thickness, spacing and reinforcement of reinforced ribs of rayed concrete (RRS) as a function of the load and the rock mass quality (Grimstad et al. 2002).

GEOPHYSICAL TECHNIQUES

Seismic Refraction & Reflection Technique

The technique involves initiation of seismic compression wave on ground by an energy source and measurement of the propagation time interval, as it is refracted from the underground and detected at the surface by an array of geophone spread. Since seismic compression wave velocity is controlled by the fundamental parameters of elastic strength and density, it serves as an index of rock quality.

In Seismic reflection method the reflected seismic waves from different layer boundaries are recorded. The seismic waves are reflected from different boundaries where the acoustical impedance (Product of density and seismic velocity) changes.

Utility

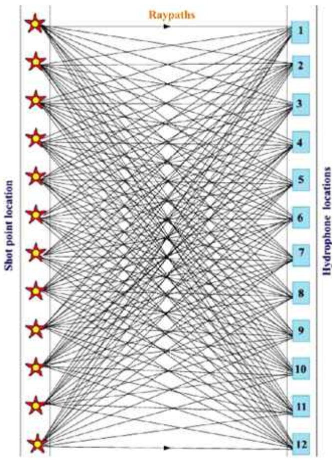
- Delineating overburden stratification.
- Estimating depth-to-bedrock and generating continuous bedrock profile.
- Identifying zone of weathering and detecting localized features like faults/shear zone and buried channel.
- Assessing rock quality/condition, rippability and soil compactness and excavation condition.
- Dynamic elastic parameter computation through compressional and shear wave propagation study.
- Construction material survey.
- Subsurface study over water covered areas using hydrophones.

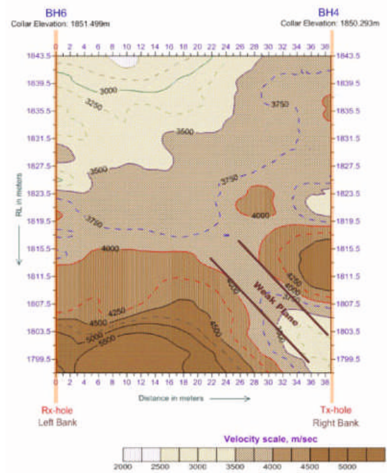
Representative Field values of Vp for various materials

Material	Vp(m/s)
Air	330
Damp Loam	300-750
Dry Sand	459-900
Clay	900-1800
Fresh, shallow water	1430-1490
Saturated, loose sand	1500
Basal/lodgments till	1700-2300
Weathered igneous and metamorphic rock	450-3700
Weathered sedimentary rock	600-3000
Shale	800-3700
Sandstone	2200-4000
Metamorphic rock	2400-6000
Unweathered basalt	2600-4300
Dolostone and Limestone	4300-6700
Unweathered granite	4800-6700
Steel	6000

Seismic Tomography Technique

Seismic tomography involves sub-surface scanning in order to develop map of the seismic velocity distribution. In cross-hole seismic tomography, seismic signals are generated through an energy source and these are picked up by the 3D accelerometers/pickups placed in whole or on surface. The data interpretation involving inverse algorithms is carried out to generate 2D/3D illustration of the scanned area, highlighting the irregularities of which affords rock mass characterization and





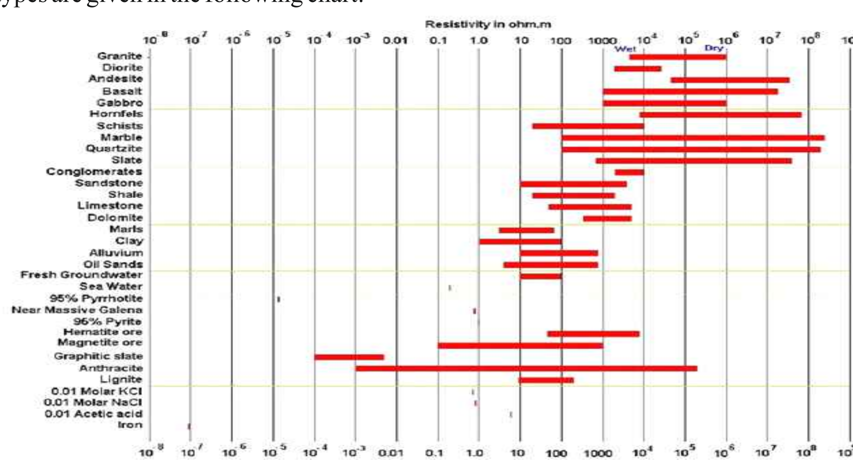
assessment of strength parameters of the medium.Precise in-situdetermination of seismic velocity (both compression and shear waves) for rock quality assessment and computation of dynamic elastic parameter and rockmass characterization.

Fig. Schematic layout of ray path along which travel-time is recorded in a cross-hole tomography survey and Seismic (P-wave) Velocity Tomogram

Utility

- Demarcating bedrock configuration.
- Defining subsurface geology and disposition of the strata.
- Delineating zones of weakness: like shear zones/seams and fractures/ fissures/cavities.
- Checking concrete structures for detecting weak zones, etc.
- Investigation of underground structure sites and study of effective grouting.

Geo-Electrical resistivity Technique: The method relies on measuring subsurface variations of electric current flow. Various subsurface materials have characteristic resistivity which can be used in assessing lithology. The resistivity values of some rock types are given in the following chart:



Utility

- Estimating watertable and delineating subsurface water bodies
- Ground resistivity measurement, specially depth-wise estimation of resistivity zonation helpful for adequate earth-mat designing.
- Complimenting seismic studies in mapping lateral and vertical changes in subsurface material through sounding and profiling, demarcating subsurface lithology, bedrock configuration and zones of weaknesses etc.
- Ground water study i.e. salinity and water quality assessment.

Resistivity Imaging System

This is a new technique where continuous 2D/3D data is collected utilizing an automatic switching system. The subsurface sections in terms of resistivity values are prepared using software based on finite difference method. The resistivity values are then interpreted in terms of lithology. The technique is useful in rockmass assessment, ground water studies and detection of leakage & cavities.

Ultrasonic Technique

These techniques involves measurement of propagation velocity of high frequency compressional and shear wave pulses by means of transducers and utilizing wave form monitoring oscilloscope system. The technique enables laboratory and in-situ determination of dynamic elastic parameters and helps in estimating static parameters empirically. And,in conjunction with direct wave measurements, it enables assessment of RQD and Q-values as well.

Ground Probing Radar (GPR)

The GPR is a high resolution electromagnetic system developed recently and is based on reflection of VHF wave impulses by the underground anomalies, which are captured by the antenna. The geo-RADAR records the time taken by each transmitted signal to complete the cycle in order to calculate the anomalous features and displays the result graphically. The high resolution profiling system has specific utility in delineating features underground and in concrete structures for small depth.

Gravity Method

It is based on the measurement of the gravitational anomaly due to variation in the density in the earth's crust. The technique has specific utility in delineating fissures/cavities and demarcating deep structural features under favorable conditions.

Magnetic Methods

The different rocks have different type of intensity of magnetizations. This intensity of magnetization can be used to detect the different formations. Most of the magnetometers used for measurement of magnetization intensity are compact devices and can be mounted on aircrafts for faster coverage of area. After applying suitable corrections different magnetic anomalies can be interpreted in terms of different geological structures.

Geophysical well Logging Methods

The different logging tools can be lowered into a drill hole to detect properties of rock through which it passes. The well logging tools give precise information of different geological formations. The most widely used well logging tools measure seismic velocities, resistivities, radioactive properties and temperature of different formation. Different combinations of logging methods can be used to determine lithology, density and porosity of the medium.

Electromagnetic Method

EM exploration is based on the fact that electric currents are introduced in the conductors subjected to an EM field, and the presence of these current can be detected by measuring the changes, they cause in the electromagnetic field in their vicinity. In this method two coils are used, one for transmitting an EM field and other is used as receiver coils. The transmitted field penetrates the surface and induces eddy currents in the encountered conductive material. The receiver measures these eddy currents

Induced Polarization Method

The tendency of rockmass to become polarized in the presence of electric field is used in this method. Polarization results from a concentration of positive electric charge on one side of the material and negative charge on the opposite side. The polarization can be natural or induced on electric current to flow in the ground; rocks containing metallic ions get polarized. Measurement of time required dissipating this polarization is used for search of different geological formations.

Blast Monitoring Studies

Safe charge limits for excavation of different structures can be estimated utilizing vibration-monitoring studies. The elastic waves generated by blasting give rise to ground motion which depends upon the site constants. These site constants can be determined utilizing the blasting seismograph and site-specific attenuation equation can be estimated. Utilizing these attenuation equation safe charge limits for various structures in terms of peak particle velocity can be determined.

ENGINEERING PROPERTIES OF ROCKS

Sl. No.	Type	Average Engineering Properties						
10		**Specific Gravity**	**Compressive Strength Kg/CM²**	**Shear Strength Kg/Cm²**	**Tensile Strength Kg/Cm²**	**Porosity Percent**	**Resistance to abrasion percent**	**Modulus of elasticity Kg/Cm²**
				Class : Igneous Rocks				
1.	Granite	2.63-2.75	1000-2500	140-500	70-250	0.44	43.9-87.9	$2x10^5$-$6x10^5$
2.	Granodiorite	2.8-3.0	-	-	-	0.5	-	-
3.	Syenite	2.6-2.8	350-500	-	-	1.38-1.54	-	$6x10^5$-$8x10^5$
4.	Diorite	2.8-3.0	1800-3000	-	150-300	0.25	-	$7x10^5$-$10x10^5$
5.	Gabbro	2.9-3.2	1800-3000	-	150-300	0.1-0.2	-	$7x10^5$-$11x10^5$
6.	Basalt (Deccan Trap)	2.6-3.0	1500-3000	200-600	100-300	0.1-1.0	14.86-18.92	$6x10^5$-$10x10^5$
7.	Dolerite	3.0-3.05	2000-3500	250-600	150-350	0.1-0.5	-	$8x10^5$-$11x10^5$
8.	Rhyolite	2.40-2.60	-	-	-	4.6	-	-
9.	Trachyte	2.60-2.85	820	-	-	-	19.5	-
10.	Andesite	2.2-2.6	1300-2500	-	-	0.1-11	-	-
				Class: Sedimentary Rocks				
1.	Sandstone	1.85-2.7	200-1700	80-400	40-250	5-25	16-29	$0.5x10^5$-$8x10^5$
2.	Limestone & Dolomite	2.14-2.8 (Limestone) 2.5-2.8 (Dolomite)	300-2500 (Limestone) and (Dolomite)	100-500	50-250	5-20	1.3-24.1	$8x10^5$-$10x10^5$
3.	Laterite	1.85	19.23	-	-	-	-	

Class: Metamorphic Rocks

1.	Charnockite	2.7-3.0	-	-	-	-	-	$7.94x10^5$-$9.94x10^5$
2.	Gneisses	2.5-3.0	500-2000	-	50-200	0.5-1.5	-	$2.01x10^5$-$4.9x10^5$
3.	Quartzite	2.55-2.65	1550-3000	200-600	100-300	0.2-0.6	-	$9.3x10^5$
4.	Marble	2.6-2.7	1000-2500	150-300	70-200	2-4	6.7-41.7	-
5.	Khondalite	2.36-2.51	-	-	-	-	-	-
6.	Slate	2.6-2.7	1000-2000	-	70-200	0.1-1.0	-	-
7.	Phyllite	2.6-2.8	-	-	-	-	-	-
8.	Schists	2.31-3.04	400-950	-	-	-	-	1.8x105-3.4x105

Appendix- II

APPARENT DIP CHART
Apparent Dips (degrees) in the Line of Section

Angles between line of section and strike of strata / True Dip (Degree)	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
5	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0	8.5	10.0	13.0	18.0	26.0	44.0
10	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.5	10.0	12.0	14.0	16.5	20.0	25.0	32.0	44.0	62.0
15	1.5	3.0	4.0	5.5	7.0	8.5	10.5	12.0	15.0	17.5	20.0	24.0	29.5	35.0	43.0	55.0	70.0
20	1.5	3.5	5.5	7.0	9.0	11.0	13.5	16.0	19.0	22.5	26.0	31.0	36.0	42.5	51.0	62.0	75.0
25	2.0	4.5	6.5	9.0	11.0	13.5	17.0	19.5	22.5	27.0	31.0	36.5	42.0	48.5	57.0	67.0	78.0
30	2.5	5.0	8.0	10.5	13.0	16.0	19.0	23.0	26.0	31.0	35.0	41.0	46.5	53.0	61.0	70.5	80.0
35	3.0	6.0	9.0	12.0	15.0	18.0	23.0	26.0	29.0	34.5	39.5	45.0	50.5	57.5	65.0	73.0	82.0
40	3.0	6.5	10.0	13.5	16.5	20.0	24.0	28.0	32.0	37.5	43.0	48.0	54.0	61.0	67.0	75.0	83.0
45	3.5	7.0	11.0	14.5	18.0	22.0	26.5	31.0	35.5	40.0	45.5	51.0	56.5	63.0	69.0	76.5	83.5
50	3.5	7.5	11.5	16.0	19.5	24.0	28.0	33.0	37.5	42.5	47.5	53.0	59.0	65.0	71.0	77.5	84.0
55	4.0	8.0	12.0	17.0	21.0	25.0	30.0	35.0	39.5	44.5	49.0	55.0	60.5	66.5	72.0	78.0	84.0
60	4.5	9.0	13.0	18.0	22.0	27.0	31.5	36.5	41.0	46.0	51.0	56.5	61.5	67.5	73.0	79.0	84.0
65	4.5	9.0	13.5	18.5	23.0	28.0	32.5	37.5	42.0	47.0	52.0	57.5	62.5	68.5	73.5	79.5	84.5
70	4.5	9.0	14.0	19.0	23.5	28.5	33.5	38.0	43.0	48.0	53.0	58.5	63.5	69.0	74.0	79.5	85.0
75	5.0	9.5	14.5	19.5	24.0	29.0	34.0	39.0	44.0	49.0	54.0	59.0	64.0	69.5	74.5	80.0	85.0
80	5.0	10.0	15.0	20.0	24.5	29.5	34.5	39.5	44.5	49.5	54.5	59.5	64.5	69.5	74.5	80.0	85.0
85	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	44.5	49.5	54.5	59.5	64.5	69.5	75.0	80.0	85.0

Appendix- III-I

GEOLOGICAL LOG OF DRILL HOLE

THDC INDIA LIMITED

GEOLOGICAL LOG OF DRILL HOLE

DRILL HOLE NO. ____________
SHEET NO. ____________

PROJECT ____________
STATE ____________
HOLE LOCATION ____________
CO-ORDINATES ____________
TOTAL DEPTH ____________

DRILLING PERIOD ____________
GROUND EL. ____________
COLLAR EL. ____________
INCLINATION ____________
BEARING ____________

ANGLE WITH HORIZONTAL ____________
BIT TYPE ____________
DRILL MACHINE ____________
LOGGING DATE ____________

DEPTH	ELEVATION(m)	LITHOLOGY		WEATHERING(W)	STRUCTURAL CONDITION			% CORE RECOVERY	R Q D%	FRACT. FREQUENCY/M	CASING	WATER LEVEL	WATER LOSS	PERCOLATION TEST				SIZE / TYPE OF BIT	SIZE OF HOLE	PERMEABILITY	DRILLING RATE (Min/m)	SPECIAL-OBSERVATIONS AND INTERPRETATIONS
		DESCRIPTION	LOG		SIZE OF CORE PCS (mm)	LOG	DESCRIPTION				OTHER PX HX NX		NIL. PART FULL	TEST SECTION	EFFECT PR (KG/CM²)	WATER LOSS L/MIN/M	FLOW TYPE LUGEON					
0m																						
1																						
2																						
3																						
4																						
5																						
6																						
7																						
8																						SCALE:-
9																						
10																						

LOGGED BY:
CHECKED BY:

APPROVED BY:
DRAWING NO.:
DATE:

Appendix-III-2

BASIC DIMENSIONS OF DRILL RODS AND CASINGS

Drill Rod			Casing Flush Coupling	Casing Tube	Casing Coupling	Casing flush jointed	Casing	Normal Core size	Normal Core size	Normal Hole size
Size Designation	OD (mm)	ID (mm)		OD (mm)	ID (mm)		OD (mm)	ID (mm)		
RW	27.89	18.2	RX	36.50	30.23	RW	36.50	30.23	18.5	30.0
EW	34.93	25.4	EX	46.02	41.3	EW	46.02	38.10	21.5	38.0
AW	43.64	34.1	AX	57.15	50.8	AW	57.15	48.41	30.0	48.0
BW	53.98	44.4	BX	73.03	65.1	BW	73.03	60.33	42.0	60.0
NW	66.68	57.1	NX	88.90	80.9	NW	88.90	76.20	54.5	76.0
HW	88.9	77.8	HX	114.30	104.8	HW	114.30	101.6	76.0	99.0
			PX	140.74	122.30	PW	140.74	123.57	92.0	121.0
			SX	169.55	147.70	SW	169.55	151.21	112.5	146.0
			UX	195.12	176.20	UW	195.12	175.79	140.0	75.0
			ZX	220.73	201.60	ZW	220.73	203.00	165.0	200.0

Appendix-IV-1

ROCK MASS CLASSIFICATION
RMR Calculation sheet

Project...............................

Structure/Location ....

RD. ....

Ref. No. ....

Date : ....

A. RMR PARAMETER AND THEIR RATINGS

	Parameter	Range of value					
1	Strength of intact rock material, Uniaxial Compressive strength	>250Mpa	100-250Mpa	50-100Mpa	25-50Mpa	5-25Mpa	1-5Mpa	<1Mpa
	Rating	15	12	7	4	2	1	0
2	Drill core quality-RQD	90%-100%	75%-90%	50%-75%	25%-50%	<25%		
	Rating	20	17	13	8	3		
3	Spacing of discontinuity	>2m	0.6-2m	200-600mm	60-200mm	<60mm		
	Rating	20	15	10	8	5		
4	Condition of discontinuities	Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation <1mm Slightly weathered walls	Slightly rough surfaces Separation <1mm Highly weathered walls	Slickensided surfaces or Gouge<5mm thick or Separation 1-5mm ontinuous	Soft gouge>5mm thick or Separation>5mm Continuous		

Rating			30	25	20	10	0
1	Ground Water	Inflow per 10m tunnel length (l/m)	None	<10	10-25	25-125	>125
		General condition	Completely dry	Damp	Wet	Dripping	Flowing
		Rating	15	10	7	4	0

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS

Strike and dip orientation		Very favourable	favourable	Fair	Unfavourable	Very unfavourable
Rating	Tunnel	0	-2	-5	-10	-12
Strike perpendicular to tunnel axis				Strike parallel to tunnel axis		
Drive with dip		Drive against dip				Irrespective of Strike
Dip 45°-90°	Dip 20°-45°	Dip 45°-90°	Dip 20°-45°	Dip 45°-90°	Dip 20°-45°	Dip 0°-20°
Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable	Fair	Unfavourable
RMR Value	RMR Rating	100-81	80-61	60-41	40-21	<20
48	Rock Class	I (Very Good)	II (Good)	III (Fair)	IV (Poor)	V (Very Poor)

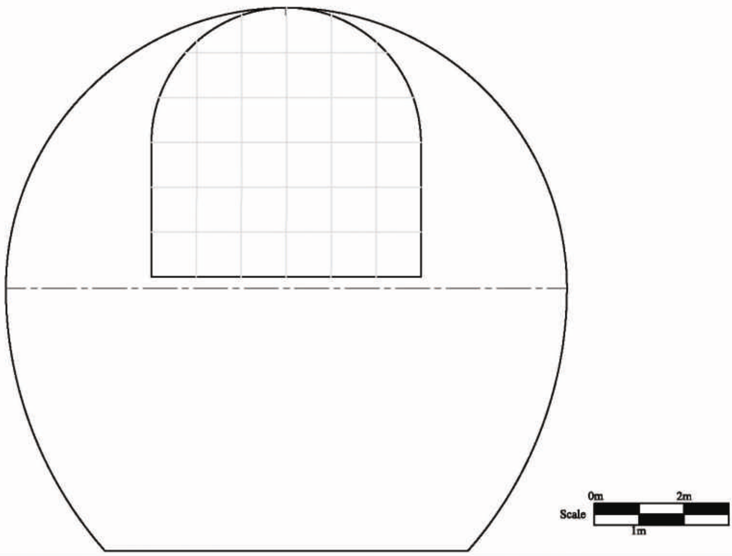
NB: Encircled values show an example of RMR derivations and classification.

Appendix-IV-2

ENGINEERING GEOLOGICAL FACE LOG

THDC INDIA LIMITED
PROJECT .....
Tunnel : Diversion Tunnel, Engineering Geological Face Map

Tunnel Drive Direction :	Invert Level :	Chainage/RD (m) :	Dia.(m):	Shape:	Sheet No.:
Date & Time :	Date & Time of Excv.:	Chainage/RD of last support (m):	Round Length (m) :		



Lithology :

As per IS 13365 - Part 1, 2003

Weathering : ☐ Fresh(W1) ☐ Slightly weath(W2) ☐ Mode weath(W3) ☐ High weath(W4) ☐ Comp weath(W5) ☐

Rockmass Strength (Mpa) : ☐ >250 ☐ 100-250 ☐ 50-100 ☐ 25-50 ☐ 5-25 ☐ 1-5 ☐ <1

RQD : ☐ 90% - 100% ☐ 75% - 90% ☐ 50% - 75% ☐ 25% - 50% ☐ <25%

3. Discontinuities	FJ/J1	J2	J3	J4/Random
Orientation				
Spacing (mm)				
Persistence (m)				
Roughness				
Aperture (mm)				
Filling				

Shear Details

Shear No.	Dip/Direction	Thickness	Infilling
SZ1			
SZ2			
SZ3			

5. RMR: **Rock Class:**

4. Ground Water : Dry Damp Wet Dripping Flowing

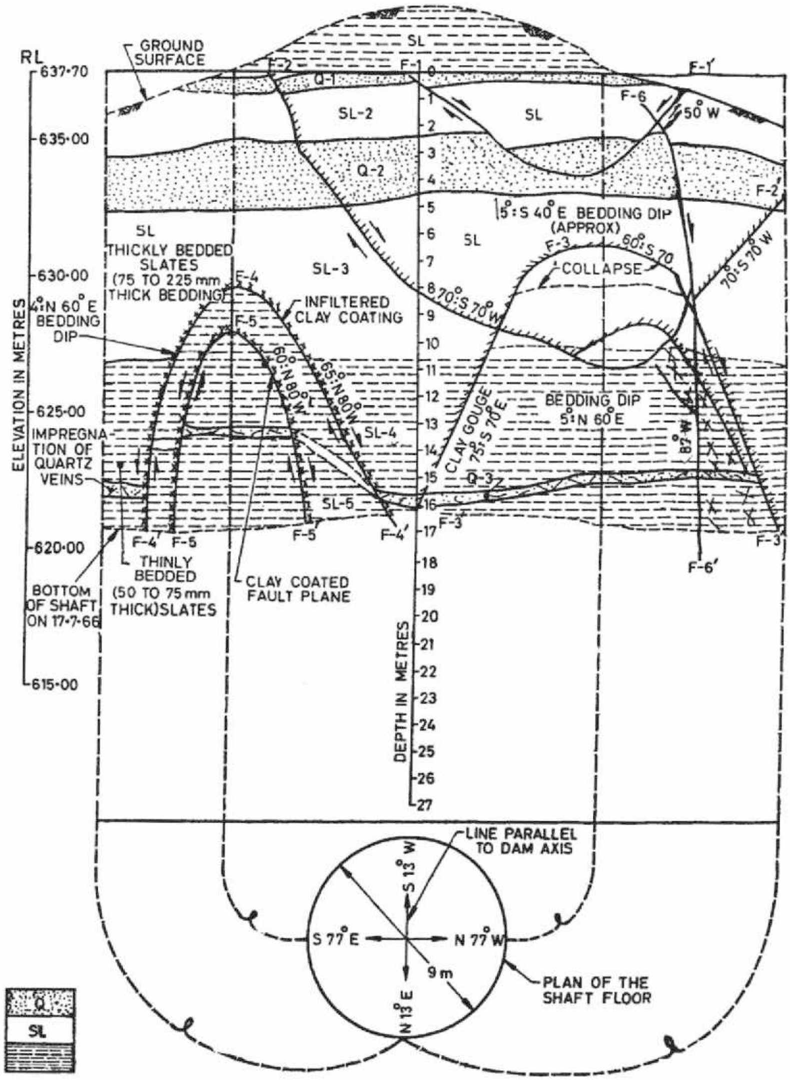
GSI (as per chart) :

Remarks /Special Observations :

Logged by:

Appendix-IV-3

A TYPICAL EXAMPLE OF 3D LOG OF A SHAFT



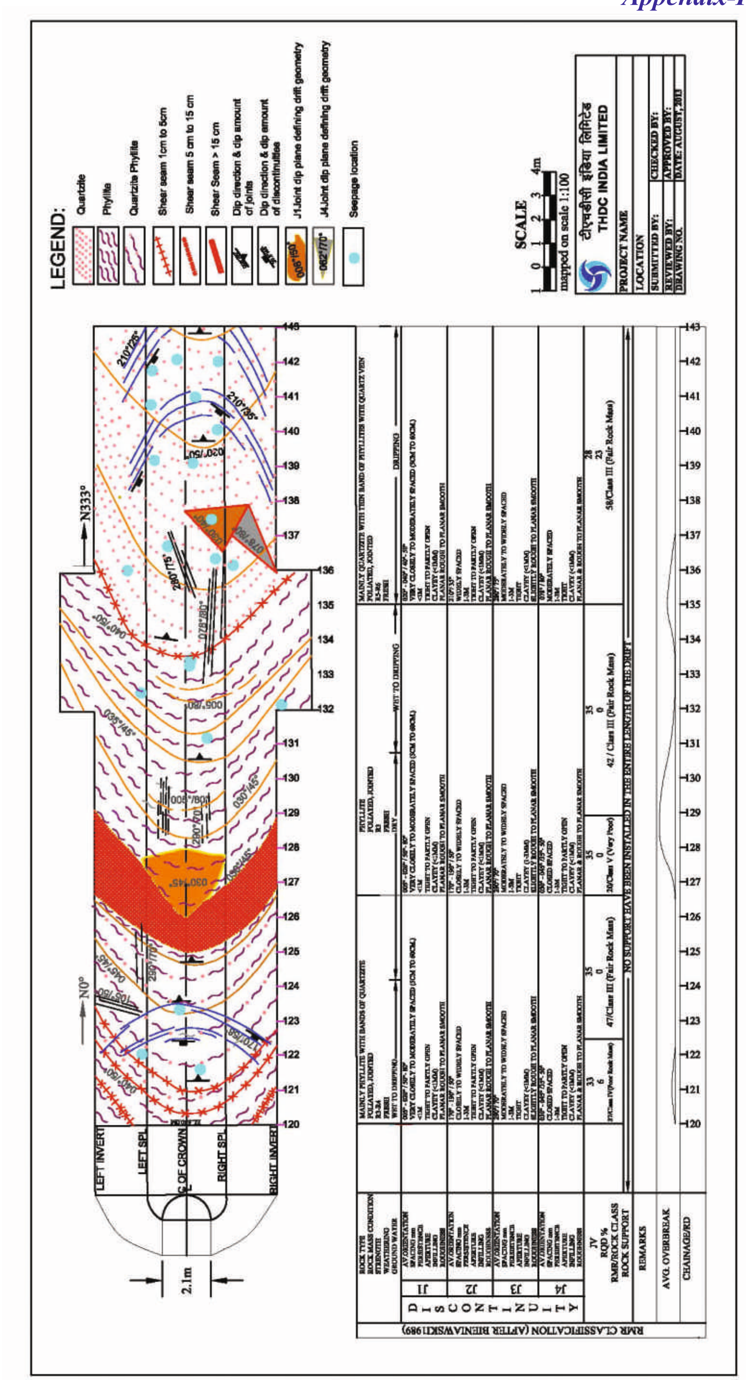
Index

Quartzite (White)
Quartzitic Shale (Thickly Bedded)
Thinly Bedded State
F-1, F-2, etc, indicate faults
Q-1, Q-2, etc, indicate quartzite (white).
SL-1, SL-2, etc, indicate quartzitic shale.

NOTE — No ground water was encountered in the shaft up to the depth illustrated.

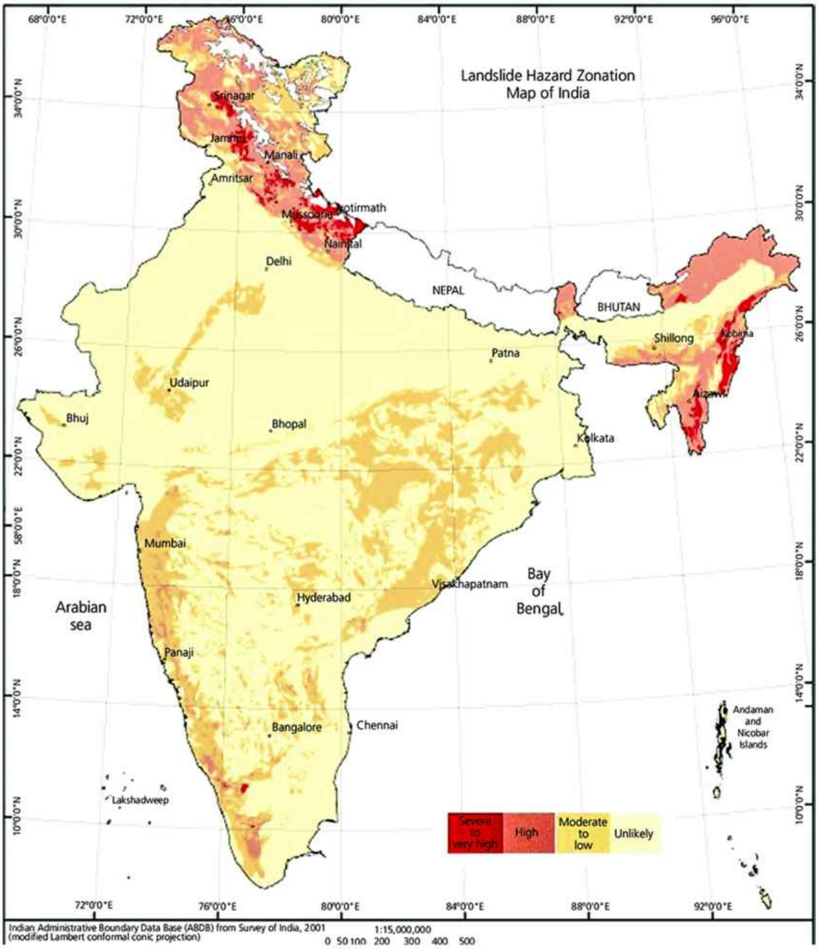
Appendix-IV-4

3D-GEOLOGICAL LOG OF DRIFT



Appendix-V-1

LANDSLIDE HAZARD ZONES IN INDIA



Source : Building Materials & Technology Promotion Council

Appendix-V-2

DATASHEET FOR RECONNOITRY INVESTIGATION OF LANDSLIDE

(Provide information / data relevant to the landslide being investigated)

No.	Dates of Field Observation	
1	Name of the slide	
2	Co-ordinates in decimal degree (in WGS 1984)*	
3	Bench Marks/Permanent reference marks, if any	
4	NH/SH No.(chainage reference)/Locality	
5	State/District/Toposheet No.	
6	Damage (Nature /Amount)	
7	Damaged features (Road, Railway, Tramission line, Building, Land (barren, cultivated, forest), Civil project, etc.)	
8	Seismic Zone & Regional Tectonic Feature	
9	Climate (Annual rainfall, snowfall, etc.)	
	History:	
10	Palaeoslide (Yes/No)	
11	Recurrence (dates or months & years)	
12	Events (Rainfall/Earthquake, etc.) linked with past Landslides (years/magnitude/intensity/etc.)	
13	Existing remedial measures and their performance	
14	Any earlier remedial measures taken, and their results	
15	Any monitoring done, and its inferences	
	Dimensions & Morphology:	
16	Landslide (Length(along slope)/Width/Height)	
17	Scarps (Strike/Dip/Height/material exposed)	
18	Striations or other lineations (type/plunge)	
19	Cracks (distribution in slide)	
20	Cracks (Length/Width/Depth/Type)	
21	Cracks (Shape/Strike/Dip/Alignment with respect to slide geometry)	
22	Depth of failure surface(Deep/Shallow/depth estimate)	
	Movement:	
23	Type of movement (Falls/Topple/Planer/Wedge/Rotational/ Flow/Lateral spread/Creep/Subsidence/Composite)	
24	Slope movement indicators (cracks, electric pole, trees etc.)	
25	Magnitude of movement (vertical and horizontal ranges)	
26	Rate of movement (Extremely Rapid, Very Rapid, rapid, moderate, slow, very slow, extremely slow)	
27	Activity (Active/Reactivated/ Suspended/Dormant/ Stabilized/Relict/Moving)	
28	Distribution (Advancing/Retrogressive/Widening/ Enlarging/Confined/Diminishing)	
29	Style (Complex/Successive/Multiple/Single)	

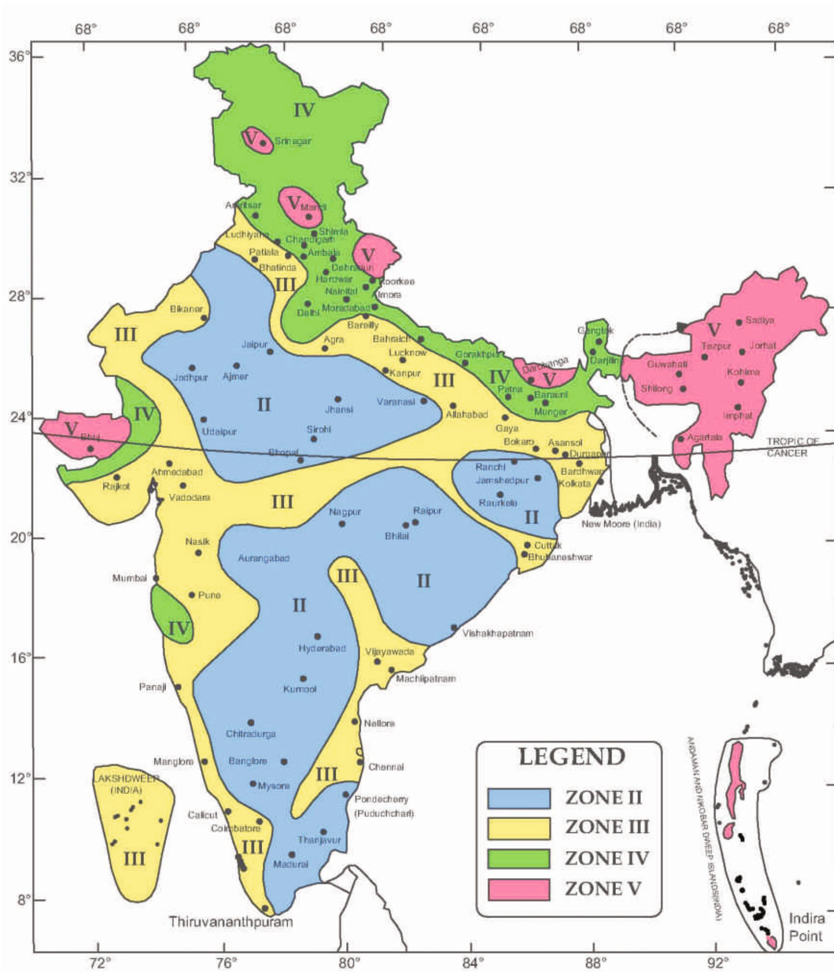
	Material & Structure:	
30	Material Involved (Rock/ soil/ rock & soil/their proportion)	
31	Soil Type & Characteristics (Field description)	
32	Soil sample (No. & Lab. tests proposed)	
33	Soil thickness (m)	
28	Bedrock surface (dip/roughness)	
29	Rocks (Lithological descriptions)	
30	Alteration/Weathering grade	
31	Structure	
32	Adverse Discontinuities (strike/dip/characteristics)	
33	Rock mass quality	
	Hydrology:	
34	Seepage (Dry/Wet/Dripping/Flowing)	
35	Details of springs/pools/water channels/watermarks (location/water level/discharge/active period etc.)	
36	Water in cracks (distribution/depth)	
37	Artificial water sources (drains, tanks, soak pits, leakage, well, etc.)	
38	Rainfall (mm) (Major event before slide/type & duration of event/Total of the season prior to slide/ If rainfall data are not available, give local information)	
	Geomorphology:	
39	Morphology of affected slope (dip/curvature/ruggedness)	
40	Affected landforms	
41	Processes leading to instability	
42	Drainage pattern and drainage anomalies in the slide zone and vicinity	
	Anthropogenic features:	
43	Land use/Land cover (barren/cultivated /forest/ rural/urban/others)	
44	Human Activity affecting slope stability	
45	Photos (with date, time, and location of photo-station)	
46	Sketch Plan & Section of the Landslide	
47	Any special observation	
	Inferences (field based):	
48	Causes & triggers of slide (List in order of importance of their role in causing the slide)	
49	Recommended action (further investigation steps/urgent safety measures/remedial approach, etc.)	
50	Features of geological interest that need to be picked up by surveyor during topographical survey, etc.	
51	Remarks	
	Signature	
	Name of Geologist:	

Appendix-V-3

	SLOPES	
Angle in Degrees	**Slope**	**Percentage Grade**
1°	1 in 57	1.75%
2°	1 in 29	3.48%
3°	1 in 19	5.22%
4°	1 in 14	6.95%
5°	1 in 11	9.09%
6°	1 in 9.5	10.51%
7°	1 in 8.1	12.27%
8°	1 in 7.1	14.05%
9°	1 in 6.3	15.838%
10°	1 in 5.7	17.63%
11°	1 in 5.0	20%
14°	1 in 4.0	25%
18°	1 in 3.1	32.2%
27°	1 in 2.0	51%
45°	1 in 1	100%
50°	1 in 0.839	119.1%
55°	1 in 0.70	142.81%
60°	1 in 0.577	173.20%
65°	1 in 0.466	214.45%
70°	1 in 0.363	274.74%
75°	1 in 0.267	373.20%
80°	1 in 0.176	567.12%
85°	1 in 0.087	1143.00%

Appendix-VI

SEISMIC ZONATION MAP OF INDIA



IS: 1893 (Part-1): 2002

Note: Towns falling at the boundary of zones demarcation line between two zones shall be considered in high zone. The Seismic Zone Map presents a largescale view of the seismic zones in the country. Local variations in soil type and geology cannot be represented at that scale. Therefore, for important projects, such as a major dam or a nuclear power plant, the seismic hazard is evaluated specifically for that site. Also, for the purposes of urban planning, metropolitan areas are microzoned. Seismic microzonation accounts for local variations in geology, local soil profile, etc.

GEOMECHANICAL PROPERTIES OF ROCKMASS TEHRI HPP

Rockmass Elements						Geomechanical Properties						
Rock Mass Group	General description of rock mass	Lithology	Zone of Exogenic Alteration	In Intact rock (Laboratory test)		In rock mass (in-situ tests) Deformation					Strength	
Rock Grade			Effect of Tectonisation/jointing	Density (gm/cm^3)	Vp (km/sec)	ME (kg/cm^2)	MD (kg/cm^2)	Poisson ratio	CS (kg/cm^2)	TS (kg/cm^2)	C (g/cm^2)	Ø (°)
Group-1	Very strong, massive rock, moderately jointed	PQM and PQT	Zone III(W_0), outside the shear zone	2.72-2.82	5.4-6.0	3,80,000	75,000	0.33	40-50	1.5	8	42
Group-2	Strong rock, moderately to highly jointed, blocky	PQM and PQT	Zone II (W1) & Zone III(W0) for intensive jointing	2.72-2.82	4.5-5.3	2,70,000	35,000	0.33	40	-	2.5	40
	Moderately strong, highly jointed	PQM and PQT	Zone III(W0), outside the shear zone	2.72-2.82	4.5-5.3	2,70,000	35,000	0.28	40	1.2	2	38
	Moderately strong to weak, intensively jointed	QP	Zone II (W1) & Zone 1 and Zone III for intensive jointing	2.72-2.82	3.5-4.0	2,00,000	25,000	0.25	20	-	2	38
Group-3	Weak rock, extremely jointed, small blocky	SP (includes aa rock types affected by tectonisation)	shear zones within Zone 1 (W2)	2.65	2.0-3.0	85,000	7,500	0.25	6	0.5	1.5	37
	Very strong, extremely jointed/crushed	SP (includes aa rock types affected by tectonisation)	Shear zones within Zone 1 (W3)	2.65	1.5-2.0	20,000	2,500	0.25	2	0.2	1	33
Group-4	IV and V order shear zones	Gouge, crushed material	In zones I, II and III	2.34	1.0-1.5	-	4	0.35	-	0	0.2	24

Source : A comprehensive Geotechnical report on Tehri Dam Project, Garhwal Himalaya, India - GSI March, 1998

GEOMECHANICAL PROPERTIES OF ROCKMASS-BUNAKHA HEP

Drill hole no.	Depth (m)	Rock Type	Slake Durability (%)	Porosity (%)	UCS(MPa)		Modulus of Elasticity (GPa)		Poisson Ratio		Tensile Strength (MPa)	Point Load Index Strength (MN/m^2)	Shear Strength Parameter (Saturated)	
					Dry	Sat.	Dry	Sat.	Dry	Sat.			Coh. (MPa)	Phi (°)
DH-13	3.50-6.50	Foliated Gneiss	96.5	1.88	-	9.54	-	4.09	-	0.24	3.34	2.76	-	-
	21.50-23.0	Foliated Gneiss	-	-	-	-	-	-	-	-	-	-	2	46
	30.50-32.0	Banded Gneiss	98.75	0.6	-	16.3	-	10.84	-	0.05	4.5	3.11	2	46
	35.0-36.50	Banded Gneiss	-	-	40.37	-	7.78	-	0.46	-	10.22	-	2	47
	38.0-39.50	Foliated Gneiss	-	-	-	31.45	-	14.77	-	0.07	-	-	2	47
	48.50-51.50	Banded Gneiss	-	1.24	-	30	-	2.65	-	0.13	7.12	-	5	45
	87.50-90.50	Banded Gneiss	98.00	0.72	-	32.9	-	28.46	-	0.31	13.98	-	4	49
	90.50-93.50	Banded Gneiss	-	-	-		-	-	-	-	-	1.74	5	49
	126.5-129.5	Foliated Gneiss	-	-	-	31.62	-	11.42	-	0.07	-	-	6.2	38
	132.5-135.5	Foliated Gneiss	-	-	-	-	-	-		-	-	1.73	6.2	38
DH-15	56.0-59.0	Amphibolite Gneiss	99.5	0.76	-	35.38	-	36.59	-	0.17	7.79	6.28	5.1	44
	62.0-65.0	Amphibolite Gneiss	-	-	-	-	-	-	-	-	-	-	5.1	44
	65.0-68.0	Amphibolite Gneiss	-	-	-	-	-	-	-	-	-	-	5.1	44
	93.5-96.5	Schistose Quartzite	99.5	0.72	-	33.81	-	24.54	-	0.29	12.45	4.19	-	-
	108.5-111.5	Amphibolite Gneiss	-	-	53.09	58.29	22.01	19.58	0.35	0.13	-	2.13	6	45
	117.5-120.0	Calc-silicate Gneiss	-	-	-	-	-	-	-	-	-	-	6	45
	128.0-129.5	Foliated Gneiss	-	-	-	-	-	-	-	-	-	-	3	42
	138.5-141.5	Banded Gneiss	-	0.95	-	18.99	-	4.07	-	0.33	-	1.4	3	42
DH-16	32.0-33.5	Foliated Gneiss	-	-	-	-	-	-	-	-	-	-	6	43
	38.0-39.0	Foliated Gneiss	98.25	0.85	-	-	-	-	-	-	-	2.78	6	43
	64.0-65.0	Amphibolite Gneiss	-	-	-	43.87	-	21.16	-	0.1	5.05	-	-	-
	67.0-68.5	Amphibolite Gneiss	-	-	-	50.06	-	38.95	-	0.8	6.25	-	-	-

DH-17	52.0-52.50	Amphibolite Gneiss	98	0.63	-	35.78	-	34.74	-	0.13	10.2	6.45	-	-
	75.0-75.50	Schistose Quartzite	98.5	0.65	-	40.02	-	37.73	-	0.21	-	4.21	-	-
DH-18	43.0-45.0	Banded Gneiss	98.5	0.8	-	46.74	-	35.78	-	0.22	8.93	7.92	-	-
DH-19	82.0-83.0	Banded Gneiss	98	0.55	-	51.5	-	30.18	-	0.16	6.07	-	-	-
DH-20	38.0-38.50	Foliated Gneiss	-	0.8	-	10.34	-	10.31	-	0.28	-	2.5	2	44
	39.5-40	Foliated Gneiss	-	-	-	-	-	-	-	-	-	-	2	44
	68.0-69.50	Banded Gneiss	99	0.72	-	37.31	-	5.57	-	0.12	6.49	4.8	-	-
DH-21	3.50-5.0	Overburden	97.75	1.2	-	10.39	-	4.13	-	0.06	6.77	1.5	4.1	34
	12.50-14.0	Foliated Gneiss	-	-	-	-	-	-	-	-	-	-	4.1	34
	23.0-24.5	Foliated Gneiss	98	0.71	-	13.29	-	5.16	-	0.25	6.85	-	-	-
DH-22	12.5-14.0	Foliated Gneiss	97.25	0.6	-	6.94	-	5.64	-	0.15	1.5	2.1	2	35
	17.0-18.5	Foliated Gneiss	-	-	-	-	-	-	-	-	-	-	2	35
	71.0-72.0	Banded Gneiss	97.5	0.61	-	46.08	-	52.9	-	0.07	14.28	-	-	-
	113.5-115.0	Banded Gneiss	98	0.45	-	21.59	-	7.71	-	0.07	11.84	-	-	-
DH-23	21.0-22.5	Banded Gneiss	98	0.76	-	42.38	-	15.36	-	0.2	11.48	4.5	-	-
	28.5-30.0	Foliated Gneiss	-	-	-	27.25	-	14.7	-	0.03	-	-	-	-

Source : Detailed Project Report 2012

Appendix-IX

GEOMECHANICAL PROPERTIES OF ROCKMASS-VPHEP

Summary of basic intact rock strength tests - VPHEP

Rock type	*UCS (MPa)*				*E (GPa)*			
	No	min	mean	max	No	min	mean	max
Amphibolite								
Amphibolite gneiss								
Augen gneiss	4	41.3	46.5	52.5	4	16.7	22.5	31.5
Calc silicate gneiss								
Dolomite	30	20.6	75.2	219.7	11	3.1	14.7	39.1
Ferruginous quartzite	1	17.3	17.3	17.3				
Gneiss	5	18.1	87.4	126.2				
Magnesite	3	39.8	47.0	55.1				
Quartzite	55	19.9	73.9	216.4	29	3.0	9.6	19.7
Slate	64	8.4	66.1	222.6	18	3.6	15.9	44.4
Slate/dolomite								
Talcose quartzite	2	15.9	32.6	49.3				
Rock type	*PLI axial (MPa)*				*PLI diametral (MPa)*			
	No	min	mean	max	No	min	mean	max
Amphibolite								
Amphibolite gneiss								
Augen gneiss								
Calc silicate gneiss								
Dolomite	12	3.5	6.1	7.8	8	0.7	2.5	4.2
Ferruginous quartzite								
Gneiss								
Magnesite								
Quartzite	17	3.2	6.0	8.8	9	2.8	3.6	4.6
Slate	20	0.8	7.2	11.6	21	0.1	1.5	4.3
Slate/dolomite								
Talcose quartzite								
Rock type	PLI lump (MPa)				σ_t (MPa)			
	No	min	mean	max	No	min	mean	max
Amphibolite	24	1.9	6.8	10.5				
Amphibolite gneiss	8	3.5	7.7	16.4				
Augen gneiss					12	3.7	6.0	8.3
Calc silicate gneiss	10	3.0	6.5	9.8				
Dolomite	53	0.9	4.4	11.1	34	1.0	9.6	42.2

Ferruginous quartzite								
Gneiss	11	3.6	5.9	10.8				
Magnesite	10	4.7	6.7	8.7				
Quartzite	42	2.2	5.4	9.8	53	3.8	13.5	22.1
Slate	25	0.9	3.4	7.2	39	4.7	11.1	17.2
Rock type	CAI							
	No	min	mean	max	Abrasivity scale			
Amphibolite	2	4.1	4.4	4.6	Extremely abrasive			
Amphibolite gneiss								
Augen gneiss								
Calc silicate gneiss								
Dolomite	5	2.0	2.3	2.6	Very abrasive			
Ferruginous quartzite								
Gneiss								
Magnesite	2	2.9	3.0	3.0	Very abrasive			
Quartzite	4	6.2	6.8	7.3	Quartzitic			
Slate	5	1.2	1.9	2.3	Medium to very abrasive			
Slate/dolomite	3	1.6	2.1	2.5	Medium to very abrasive			
Talcose quartzite								

UCS = Uniaxial compressive strength; E = Modulus of elasticity

PLI = Point load index; σ_t = Brazilian tensile strength

CAI = Cerchar Abrasivity Index

Source : Geotechnical Baseline Report of VPHEP, version 6.2

Summary of triaxial tests						
Location	*Rock type*	*Condition*	*Shear strength*		*Hoek-Brown parameters*	
			c MPa	Ø	sci MPa	mi
Power House	Slate	Dry	11.4	40	75	9.5
Power House	Slate	Saturated	8.0	36	59	4.0
Power House	Dolomite	Dry	14.4	37	74	6.7
Power House	Dolomite	Saturated	12.6	37	57	9.7
Desilting complex	Quartzite	Dry	18.4	48	148	16.3
Desilting complex	Quartzite	Saturated	14.5	44	127	12.7
c = cohesion	Ø = friction	sci = intact rock strength		mi = Hoek-Brown parameter for intact rock		

Results of in situ tests on deformability and shear strength				
Plate load tests			*Average results for 80 tonne load on 60 cm plate*	
Location	*Rock type*	*Orientation*	*Modulus of deformation GPa*	*Modulus of elasticity GPa*
Left bank drift	Quartzite	Vertical	2.7	3.9
Right bank drift	Quartzite	Horizontal	1.2	5.1
Right bank drift	Quartzite	Vertical	10.2	13.7
PH drift	Dolomite	Vertical	3.4	5.2
PH drift	Dolomite	Horizontal	1.2	2.0

Appendix-X

SHEAR STRENGTH OF FILLED DISCONTINUITIES AND FILLING MATERIALS (AFTER BARTON 1974)

Rock	Description	Peak c' (MPa)	Peak ϕ°	Residual c' (MPa)	Residual ϕ°
Basalt	Clayey basaltic breccia, wide variation from clay to basalt content	0.24	42		
Bentonite	Bentonite seam in chalk	0.015	7.5		
	Thin layers	0.09-0.12	12-17		
	Triaxial tests	0.06-0.1	9-13		
Bentonitic shale	Triaxial tests	0-0.27	8.5-29		
	Direct shear tests			0.03	8.5
Clays	Over-consolidated, slips, joints and minor shears	0-0.18	12-18.5	0-0.003	10.5-16
Clay shale	Triaxial tests	0.06	32		
	Stratification surfaces			0	19-25
Coal measure rocks	Clay mylonite seams, 10 to 25 mm	0.012	16	0	11-11.5
Dolomite	Altered shale bed, ± 150 mm thick	0.04	1(5)	0.02	17
Diorite, granodiorite and porphyry	Clay gouge (2% clay, PI = 17%)	0	26.5		
Granite	Clay filled faults	0-0.1	24-45		
	Sandy loam fault filling	0.05	40		
	Tectonic shear zone, schistose and broken granites, disintegrated rock and gouge	0.24	42		
Greywacke	1-2 mm clay in bedding planes			0	21
Limestone	6 mm clay layer			0	13
	10-20 mm clay fillings	0.1	13-14		
	<1 mm clay filling	0.05-0.2	17-21		
Limestone, marl and lignites	Interbedded lignite layers	0.08	38		
	Lignite/marl contact	0.1	10		
Limestone	Marlaceous joints, 20 mm thick	0	25	0	15-24
Lignite	Layer between lignite and clay	0.014-.03	15-17.5		
Montmorillonite Bentonite clay	80 mm seams of bentonite (mont-morillonite) clay in chalk	0.36 0.016-.02	14 7.5-11.5	0.08	11
Schists, quartzites and siliceous schists	100-15- mm thick clay filling	0.03-0.08	32		
	Stratification with thin clay	0.61-0.74	41		
	Stratification with thick clay	0.38	31		
Slates	Finely laminated and altered	0.05	33		
Quartz / kaolin / pyrolusite	Remoulded triaxial tests	0.042-.09	36-38		

Appendix-XI-1

LOAD CARRYING CAPACITY OF THE ANCHOR/BOLT [IS : 14448 - 1997 (Reaffirmed 2012)]

The load carrying capacity of the anchor/bolt will be governed by the worst of the following three failure criteria

1. Failure of the anchor in tension

Dia of reinforcement =	d	25.00	mm
Tensile strength of the steel =	s_{st} (Fe 500)	500.00	Mpa
Factor of safety for steel =	F_s	1.30	
Load carrying capacity =	$F_1 = s_{st}.p.d^2/(4.F_s)$	188.80	kN

2. Failure of the bond between between Grout and Anchor

	$t_a = f_c/10 < 2.5$ Mpa (Deformed bar)		
Bond strength between anchor and grout =	ta=$f_c/15 < 1.2$ Mpa (Plain bars)	1.50	Mpa
Factor of safety =	F_a	1.50	
Length of anchor =	L	4.00	m
Load carrying capacity =	$F_2 = p.d.L.t_a/F_a$	314.16	kN

3. Failure of the bond between between Grout and Rock

	t_f (0.35 -0.70 Mpa for RMR =0 to 40)		
	(0.70 -1.05 Mpa for RMR =41 to 80)		
Bond strength between rock and grout =	(1.05 -1.40 Mpa for RMR =81 to 100)	0.40	Mpa
Factor of safety =	F_g	1.00	
Length of anchor =	L	4.00	m
Dia of Hole =	D=1.5*d	37.50	mm
Load carrying capacity =	$F_2 = p.D.L.t_f/F_g$	188.50	kN

So, Ultimate Load carrying capacity, P = Minimum of F_1, F_2 & F_3 188.50 kN

Based upon the sample calculation shown above the load carrying capacity of the anchors (in kN) having different dia and length is tabulated below for following strength parameters

s_{st} = 500 Mpa t_a = 1.5 Mpa t_f = 0.4 Mpa
FoS = 1.3 FoS = 1.5 FoS = 1

Dia. (mm) / Length (m)	25	32	36	40	50	60
1	47.12	60.32	67.86	75.40	94.25	113.10
1.5	70.69	90.48	101.79	113.10	141.37	169.65
2	94.25	120.64	135.72	150.80	188.50	226.19
2.5	117.81	150.80	169.65	188.50	235.62	282.74
3	141.37	180.96	203.58	226.19	282.74	339.29
3.5	164.93	211.12	237.50	263.89	329.87	395.84
4	188.50	241.27	271.43	301.59	376.99	452.39
5	188.80	301.59	339.29	376.99	471.24	565.49
6	188.80	309.33	391.49	452.39	565.49	678.58

Appendix-XI-2

PRE-TENSIONING OF ROCK BOLTS

Failure of the anchor in tension

Dia of rock bolt	=	d		
Yield stress of the steel	=	σ_y	500.00	Mpa
Factor of safety for steel	=	F_s	1.3	
Load carrying capacity	=	$F_1 = s_{st}.p.d^2/(4.F_s)$		

Pre-tensioning:

Class-I	~	80%	of Bolt capacity
Class-II	~	60%	of Bolt capacity
Class-III	~	40%	of Bolt capacity
Class-IV	~	10%	of Bolt capacity
Class-V	~	10%	of Bolt capacity

Dia of Rock Bolt (mm)	Tensile Load Capacity (kN) 189	Max-Pre-Tension (kN)	Pre-Tension (kN)				
			Class-I	Class-II	Class-III	Class-IV	Class-V
25	189	150	150	113	76	19	19
32	309	240	240	186	124	31	31
36	391	300	300	235	157	39	39

Appendix-XII

UNIT CONVERSION FACTORS

UNITS OF DISTANCE

To Convert	To	Multiply by
ft	in	12
ft	m	0.3048
in.	mm	25.40
m	ft	3.281
mm	in.	0.03937

UNITS OF STRESS AND PRESSURE

To Convert	To	Multiply by
Atmosphere	kPa	101.3
bar	kPa	100
kgf/cm^2	kPa	98.07
kPa	Atmosphere	0.009869
kPa	bar	0.01
kPa	kgf/cm^2	0.01020
kPa	metric ton/m^2	0.1020
metric ton/m^2	kPa	9.807

Appendix-XIII

DEFINITION [IS: 11358 - 1987 (Reaffirmed 2005)]

1 **A Line (Minimum Excavation Line) -** A dimensional line in a tunnel inside of which rock projections are not permitted, or

It is the line within which no unexcavated material of any kind and no supports other than permanent structural steel supports shall be permitted to remain.

2 **Acoustic Emission -** See microseismic noise.

3 **Active Fault -** A fault along which there is recurrent movement that is usually indicated by small, periodic displacement or seismic activity.

4 **Adit -** A nearly horizontal passage leading from the surface to an underground chamber or Passage connecting two such chambers, *or*

Tunnel into an abutment for exploratory or test purpose, *or*

Opening in the face of a dam for access to galleries or operating chambers, *or*

Access tunnel to a tunnel for construction or maintenance purposes.

5 **Air Lock -** A compartment in which air pressure can be equalized to the compressed air inside a shield-driven tunnel as well as the outside air to permit passage of men and materials.

6 **Allowable Bearing Pressure (qa) -** It is the allowable pressure transmitted by a foundation to the rock mass such that no damage occurs either in the structure or in the rock mass. It is based upon safe bearing pressure (satisfying criteria of shear, total and differential settlement and tilt), correction factors, and past experience and judgement of experts.

7 **Angle of Draw Subsidence -** Jt is defined as the angle between the vertical and the line connecting the limit of excavation with the point of zero subsidence. This is cal1ed the limiting angle of influence.

8 **Angle of Friction of Fractures -** It is the sliding angle (tangential) of friction at normal pressure of 10 kg/cm^2 across joints. It is classified as A1, A2, A3, A4. As for angle of friction of fractures of >45, 35-45,

25-35,15-25 and < 15", respectively. This notation is used in basic geotechnical description (BGD). The sliding angle of friction of joints is further measured in two parts as follows:

a) *Peak Sliding Angle of Friction* - It is the sliding angle of friction for the maximum or peak shear strength observed in a shear test across a joint.

b) *Residual Sliding Angle of Friction* - It is the sliding angle of friction for the state of residual strength of a joint which may be obtained by subjecting the joint to excessive slip such that no further reduction in shear strength takes place.

9 **Angle of Internal Friction, Peak ($Ø_p$) -** Angle of internal friction (that is, slope of strength envelope) corresponding to maximum shear stress in shear stress/displacement plot.

10 **Angle of Internal Friction, Residual ($Ø_r$) -** Angle of internal friction corresponding to shear stress at large displacement (that is, corresponding to residual shear strength).

11 **Anisotropy -** A condition of a material having different properties in different directions. For example, the state of geologic strata of transmitting sound waves with different velocities in vertical and horizontal directions. Situation of a material having different moduli of deformation in different directions.

11.1 **Transverse Anisotropy -** The anisotropy of sedimentary deposits of rock mass is of very special nature and is called transverse anisotropy. (Only five elastic constants are sufficient to define the anisotropy of the rock mass).

12 **Anticline -** An arch-like fold (up-fold) in rocks, with the beds dipping in opposite direction from the crest.

13 **Apron -** A floor with lining of concrete, timber or other resistant material at the toe of adam, bottom of a spillway or chute to preventerosion from falling water of turbulent flow.

14 **Arch -** The configuration of the upper part of a tunnel section above the spring line or the crown or the curved roof of an under ground opening (tunnel).

15 **Arching -** The transfer of load by shear from the yielding part of a rock mass to the adjoining less yielding or restrained part of mass.

16 **Artesian Condition -** Ground water that is under sufficient pressure to rise above the level at which it is encountered by a well, but which does not necessarily rise to or above the surface of the ground.

17 **As parities -** These are small undulations along a discontinuity. There are two types of as parities called primary and secondary as parities. Primary as parities are major as parities while secondary as parities are micro-undulations of the primary as parities.

18 **Attenuation -** The amplitude of waves decrease as they travel through rock mass. This reduction in amplitude is known as attenuation. Attenuation is energy loss with distance per cycle.

19 **Axial Young's Modulus (E) -** It is the ratio of the axial stress change to the axial strain produced by the stress change for a cylindrical specimen tested in uniaxial compression. It may be calculated using any of the following methods:

a) Tangential Young's Modulus, Et- This is the tangential Young's modulus at a stress level which is some fixed percentage of the ultimate strength and is generally 50 percent of the ultimate uniaxial compressive strength.

b) Average Young's Modulus, Ear - The average Young's modulus is defined as the average slope of more or less straight portion of the axial stress-strain curve.

c) Secant Young's Modulus, Eo- The secant Young's modulus is usually measured from zero stress to some fixed percentage of the ultimate strength, generally 50 percent.

20 **B Line (Pay Line) -** A dimensional line in a tunnel outside -of which excavation is not paid for, or

The B-line is that line for which payment is made to the contractor for the underground excavation done in rock using conventional method of drilling and blasting.

21 **Back Packing -** Any material (usually granular) which is used to fill the empty space between the lagging and the rock 'surface in a tunnel.

22 **Basic Geotechnical Description (BGD) -** The basic geotechnical description of rock mass is based on five parameters, namely, rock name (geological description), layer thickness, fractureintercept, uniaxial compressive strength and angle of friction of fractures. For example, a zone of rock mass may be described as Quartz - L_2, F_4, S_3, A_2, where L, F, S and A represent the last four parameters defined in the text.

23 **Basic Sliding Angle of Friction of Joints ($Ø_b$) -** It is the angle of sliding friction between flat non-dilatant rock surfaces in dry or wet conditions. It is obtained from residual tests on flat unweathered rock surfaces.

24 **Bearing Pressure (Safe) (qs) -** The load per unit area which can be safely supported by the ground (rock and/or soil).

25 **Bed Rock -** Any laser of rock under lying soil, *or*

Geologically, the term denotes material underlying drift deposits, *or*

It is the solid, undisturbed rock in place either at the ground surface or beneath superficial deposits of gravel, sand, or clay.

26 **Bedding Plane -** A plane dividing sedimentary rocks of same or different lithology. The division planes which separate the individual layers, beds, or strata marking the boundary between a bed and the bed above and/or below it.

27 **Bench -** The unexcavated rock having a nearly horizontal surface which remains after a top heading has been excavated in a tunnel.

28 **Bench Blasting -** A method of blasting in quarries and open pits. The excavation proceeds in steps or in benches and rows of blast holes are drilled parallel to the free face.

29 **Bending Strength -** An alternative term for flexural strength (see tensile strength),

30 **Blanket or Area Grouting -** The process of grouting to a specified depth for the purpose of consolidation and/or reducing permeability.

31 **Blast ability -** Index value of the resistance of a rock formation to blasting.

32 **Blasting Cap or Detonator -** A small tube containing a flashing mixture for firing explosives.

33 **Blocking -** Wood on blocks placed between the excavated surface of a tunnel or a shaft and the main bracing system.

34 **Blow-Out -** A sudden loss of a large amount of compressed air at the top of a shield.

35 **Bond Strength -** The stress required to rupture the bond in a material, or between two kinds of material cemented one to another (for example a concrete block cemented on rock).

36 **Bore Log -** The detailed record of the rocks passed through in drilling: where accurate logs constitute a valuable source of sub-surface Information.

37 **Borehole -** A hole drilled into the ground for purpose of extracting soil samples and/or rock cores for examination and testing.

38 **Borehole Extension (of Extensometer) -** Elongation in the axis of a borehole in in-siturock, due to extension.

39 **Bottom Charge -** Concentrated explosive charge at the bottom of a blast hole.

40 **Boulder -** A more or less rounded block offragment of rock and of average dimension 300mm or greater. Usually boulders are rounded by being carried or rolled along by water or ice, sometimes also by weathering in place, in which case they are known as boulders of weathering, disintegration or exfoliation.

41 **Breast Board -** Timber planks to support the face of tunnel excavation in soft ground.

42 **Breccia -** A coarse-grained elastic rock Composed of large, angular and broken rock fragments that are cemented together in a finer-grained matrix, and that can be of any composition, origin or mode of accumulation.

43 **Brittle -** A material is said to be in a brittle state or brittle under conditions in which its stability to resist load decreases suddenly with increasing deformation.

44 **Broken Zone (Around Tunnel) -** The broken zone is defined as the area bounded by the locus of points around the tunnel opening where the induced tangential stress exceeds the in-situ strength of rock mass. The rock mass is in elastic state beyond the broken zone.

45 **Buckling -** The twisting or forcing out of shape of a structural member or rock layer under compression by an excessive or eccentric load.

46 **Bulk Volume (Vb, U) -** The volume contained within the gross external dimensions of a rock specimen, denoting the volume occupied by the grains, voids and intergranular infillings.

47 **Bump (Coal Mines) -** Bump is defined asa strong seismic shock resulting from a failure ora sudden displacement at some point in the rock surrounding an underground opening.

48 **Burden -** Distance between charge and free surface in direction of throw.

49 **Burst-**To break suddenly into pieces from impact or from pressure within.

50 **Cable Anchor -** Cable are used to prestress the rock mass around large openings or anchor the civil engineering structures into the rock foundation. These anchors are known as cable anchors.

51 **Camouflet -** The underground cavity created by a fully contained explosive.

52 **Cancellation Pressure -** This is the hydraulic pressure in the flat jack at which the displacements created by cutting the slot are cancelled.

53 **Catastrophic Failure -** A failure of large rock mass giving almost no warning. A sudden failure.

54 **Cavern (Sinkhole) -** A subterranian hollow; an underground cavity (most frequent in limestone and dolomites).

55 **Cavities -** Sinkholes and other sorts of open cavities are most commonly formed in limestone, gypsum, and salt.

56 **Charge -** The amount of explosive used in a blast hole.

57 **Circular Wedge Failure -** When the material is very weak, as in a soil slope, or when the rock mass is very heavily jointed or broken, as in a waste rock dump, the failure will be defined by a single discontinuity surface and will tend to follow a circular failure path.

58 **Clastic Rock -** A consolidated sedimentary rock composed principally of detritus transported into its place of deposition (for example, sandstones and shales as distinct from limestones and anhydrites).

59 **Clay -** Soil consisting of inorganic material, the particle size of which have diameters smaller than 0•002 mm.

60 **Coefficient of Volumetric Expansion -** This is the ratio between the increase in volume of rock mass and its initial volume.

61 **Cohesion (c) -** The property of rock particles to bind together, given by the vertical interceptor strength envelope, that is, of shear strength versus normal stress plot.

62 **Compacting Zone (Around Tunnel) -** zone within rock mass having tendency to undergo compaction near supports in squeezing ground.

63 **Condition of Joints -** This parameter includes roughness of joint surfaces, their continuity their opening or separation (distance between the surface), the infilling (gouge) material, and weathering of the wall rock.

64 **Conformity -** The relationship of adjacent beds not separated by a sedimentary discontinuity.

65 **Consolidation Grouting -** See grouting.

66 **Continuum -** A continuum is a mathematical abstraction applied to a large collection of material particles.

67 **Controlled Blasting -** Blasting designed top reserve the -integrity of the remaining rocks, for example, smooth blasting or pre-splitting.

68 **Core -** Any single solid piece or rock incylindrical shape obtained by drilling process.

69 **Core Loss -** Percentage of loss of core from a drill hole with respect to the total drill run.

70 **Core Recovery -** Percentage of core recovered from a drill hole with respect to the total core run.

71 **Crack -** Rocks have small cracks which are formed either between the boundaries of the mineral grains or develop as transgranular fractures.

72 **Crater -** A pit formed on the ground surface due 10 an underground explosion.

73 **Creep -** Time-dependent deformation or strain. Deformation that occurs over a period of time when a material is subjected to constant stress at constant temperature. Slow deformation that results from long application of stress. An inperceptibly slow, more or less continuous, downward and outward movement of slope-formingrock or soil.

74 **Creep Strength -** Maximum stress required to bring about a specified amount of creep in a specified time.

75 **Critical Stress -** Maximum and minimum compressive stress on the boundary of an opening.

76 **Cross Joints -** These are the joints which generally occur in a direction normal to bedding planes. These are invariably discontinuous joints.

77 **Crown -** The highest point of the cross-section.In tunnel linings, the term is used to designate either the arched roof above spring lines, or all of the lining except the floor or invert.

78 **Crust -** The outermost layer or shell of the earth lying above the Mohorovicic discontinuity.

79 **Curtain Grouting -** The process of grouting in which one or more lines of holes arc grouted to specified depths in order to create a barrier against seepage.

80 **Cut-Off -** A wall or diaphragm of concrete, steel, grout wall, or a slurry trench or trench filled with duly compact impervious material for the purpose of reduction of seepage under a dam and rock foundation material, and to reduce uplift pressure on the base of a dam and other structural foundation.

81 **Cycle Time -** Cycle time is defined as the -time required for various processes of excavation starting from drilling and blasting to mucking and support installation.

82 **Cyclical Stress -** Repeated stressing and destressing of material.

83 **Damping -** Reduction in the amplitude of vibration of a body or system due to dissipation of energy internally or by radiation.

84 **Decomposition -** The breaking down of minerals by themselves or in rocks through chemical processes, usually related to weathering.

85 **Decoupling -** The ratio of the radius of the blast holes to the radius of the charge. In general, a reducing of the strain wave amplitude by increasing the spacing between charge and blast holes.

86 **Deformation Modulus (E_c) -** In repeated loading-unloading tests, the ratio of stress, σ to the total strain (total strain = $\epsilon_{el} + \epsilon_{ir}$) is called the modulus of deformation or compression modulus:

$$Ec = \frac{\sigma}{\epsilon_{total}} = \frac{\sigma}{\epsilon_{el} + \epsilon_{ir}}$$

This modulus is thus based on the total measured strains, that is, elastic plus inelastic (irreversible or plastic) strains, E_{el} and E_{ir}, respectively.

87 **Degree of Squeezing -** The ratio of uniaxial compressive strength (qc) of rock mass to the tangential stress (σ_t = 2p) defines the degree of squeezing which may be mild, moderate or high depending upon the value of qc/2p

88 **Delay -** Time interval (fraction of a second) between detonation of explosive charges.

89 **Density (p) -** Density of a rock is defined as its mass (m) per unit volume (V). In the civil engineering usage; however, the term density is tacitly assumed to mean the unit weight of a material.

90 **Dental Treatment -** It is the treatment in the foundation or abutment of rock mass for safety of a masonry concrete dam. Normally, shear keys are provided between the foundation and the dam to improve resistance to sliding. If there isa fault or a shear zone or a zone of weak rock in the foundation, the soft rock is excavated to required depth below the dam base and back filled with concrete.

91 **Detonation -** An extremely rapid and violent chemical reaction causing the production of a large volume of gas.

92 **Detritus -** A deposit of material produced by the weathering and disintegration of rocks that has been moved from its place of origin.

93 **Dilatancy -** Refers to a relative increase in volume for particular stress state, for example, packed sand expands when sheared.

94 **Dip -** The vertical angle that a stratum (or fault plane, or bending plane or joint plane or any planar feature), makes with the horizontal measured perpendicular to the strike of the structural surface, or

The dip at right angles to the strike, *or*

The slope of bed rock relative to the horizontal, *or*

A pronounced depression in the land surface.

95 **Discontinuity -** The general term for any mechanical discontinuity in a rock mass having zero tensile strength. It is a collective term for most types of joints, weak bedding planes, weakschistocity planes, weakness zones and faults. The ten parameters selected to describe discontinuities and rock masses are defined below:

a) *Orientation* - Attitude of a discontinuity in space. Described by the dip direction (azimuth) and dip of the line of steepest inclination in the plane of the discontinuity. Termination in solid rock or against other discontinuity reduces the persistence.

b) *Spacing* - Perpendicular distance between adjacent discontinuities. Normally refers to the mean or modal spacing of a set of joints.

c) *Persistence* - Discontinuity trace length as observed in an exposure may give a crude measure of the areal extent or penetration length of a discontinuity. Termination in solid rock or against other discontinuities reduces the persistence.

d) *Roughness* - Inherent surface roughness and waviness relative to the mean plane of a discontinuity. Both roughness and waviness contribute to the shear strength; large scale waviness may also alter the diplocally.

e) *Wall Strength* - Equivalent compression strength of the adjacent rock walls of a discontinuity, may be lower than rock block strength due to weathering or alteration of the walls. An important component of shear strength if rock walls are in contract.

f) *Aperture* - Perpendicular distance between adjacent rock walls of a discontinuity, in which the intervening space is air or water filled.

g) *Filling* - Material that separates the adjacent rock walls of a discontinuity and which is usually weaker than the parent rock.

Typical filling materials are sand, silt, clay, breccia, gouge and mylonite. Also includes thin mineral coatings and healed discontinuities, for example, quartz and calcite veins.

h) *Seepage* - Water flow and free moisture visible in individual discontinuities or in the rock mass as a whole.

j) *Number of Sets* - The number of joint sets comprising the intersecting joint system. The rock mass may be further divided by individual discontinuities.

k) *Block Size* - Rock block dimensions resulting from the mutual orientation of intersecting joint sets, and resulting from the spacing of the individual discontinuities may further influence the block size and shape.

96 **Disking (During Drilling) -** When drilling into highly stressed hard rock, it is common for the core to emerge in regular discs, which are quite unrelated to the structure of the rock. The disking occurs when tensile stress developed due to stress relief exceeds the tensile strength of core. The thickness of the disc diminishes with increasing primitive stresses.

97 **Dome -** Hemispherically shaped roof of a cylindrical underground excavation *or*

A dome is a feature in structural geology consisting of symmetrical anticlines that intersect each other at their respective apices. Intact, domes are distinct, rounded, spherical-to-ellipsoidal-shaped protrusions on the Earth's surface.

98 **Drainage Well -** A vertical shaft constructed in masonry dams to intercept seepage before it appears at the down-stream face of the dam.

99 **Drift -** A horizontal underground passage, *or*

Rock material of any sort deposited in one place after having been moved from another.

100 **Drillability -** Drillability is the measure of drilling speed at which a drill may penetrate different rocks.

101 **Drilling Conditions -** Rock drillability may be classified in five

categories; fast, fast average, average, slow average and slow. The drilling conditions depend upon hardness, texture and fracture formation of a rock mass. A quantitative classification for drilling condition is available.

102 **Drilling Pattern -** The number, position, depth and angle of the blast-holes forming the complete round in the face of a tunnel or sinking pit.

103 **Dry Density (ρd) -** The mass of a rock sample or specimen after drying to constant mass at 15^0C per unit gross volume of the sample or specimen.

104 **Ductility -** For a known or particular stress state (existing or imposed) to which a material can sustain plastic deformation without breaking or rupture. Elongation and reduction of area are common indices of ductility.

105 **Dyke -** A sheet like body of igneous rock which is discordant, that is, cuts across the bedding or structural planes of the host rock.

106 **Dynamic Elastic Modulus (E_{dyn}) -** It is the modulus of elasticity of rock mass under dynamicloads. During propagation of seismic waves through a rock mass, it is the dynamic modulus which determines the velocity of waves. The static modulus is less than the dynamic modulus. The ratio of static to dynamic modulus is called the reduction factor which can be estimated from the rock quality designation.

107 **Effective Stress -** Pore water pressure in rock is a factor affecting rock strength. The effective normal stress is generally taken equal to the difference between normal stress and the pore water pressure. This is strictly valid only where pores, cracks and fractures are interconnected.

108 **End Effect -** In a uniaxial compression test in the laboratory or in the field, there is always some friction between the specimen and the leading surfaces. This friction restricts the lateral expansion of the ends of the specimen. This effect of lateral restraint is called end effect which often gives rise to conical fragments based on each platen.

109 **Erosion -** Process whereby soil or rock mass is loosened or dissolved and removed from any part of the earth's surface. It includes weathering, solution and transportation.

110 **Escarpments or Scarps -** A steep cliff or ridge that is formed by

sudden earth movements, usually vertical but sometimes also horizontal along fault lines, *or*

Any line of cliffs, or abrupt slope breaking the continuity of a land surface, *or*

A fault line scarp is the one formed along the line of a fault.

111 **Expanding Zone -** Zone within broken zone expanding in volume or undergoing dilatation after failure.

112 **Explosives -** A substance which undergoes a rapid chemical change, with production of a large volume of gas.

113 **Face -** The solid surface of the unbroken part of the rock at the advancing end of the working place in a tunnel or adit.

114 **Factor of Safety (of Slope) -** The ratio of the total force available to resist sliding to total force tending to induce sliding.

115 **Failure -** Failing to perform an expectedaction. In a general sense, failure includes both fracture and flow.

116 **Fatigue -** Permanent structural change that occurs in a material subjected to fluctuating stress and strain. In general, fatigue failure occurs ata stress level below the elastic limit.

117 **Fault -** A fracture or a fracture zone along which there has been recognizable displacement, from a few centimetres to a few kilometres in scale. The walls are often striated and polished(slicken sided) resulting from the shear displacement. Frequently, rock on both sides of a fault is shattered and altered or weathered, resulting infillings such as breccia and gouge. Fault widths may vary from millimetres to hundreds of metres.

118 **Fault Slip -** A relative displacement of points on opposite sides of a fault measured on the surface of the fault, a minor fault, or slide.

119 **Fault Trace -** The line of intersection of a fault plane with the surface.

120 **Fault Zone -** A wide shattered belt rather than a fault plane.

121 **Fill -** Deposits of soil, rock or other material placed by man.

122 **Finite Element -** One of the regular geometrical shapes into which a body is subdivided for the purpose of numerical analysis.

123 **Fissure -** An extensive crack, breaks or fracture in the rock.

124 **Fold -** Folds are wavy undulations which are developed in the country-rocks whenever theregion is subjected to severe pressure or stress.

125 **Foliation -** The parallel disposition of the platy or flaky mineral is known as foliation. This property is developed in metamorphic rocks only.

126 **Formation -** A group of rocks with recognizable and traceable boundaries. sufficiently alike lithologically to be mapped as a unit:

a) *Massive* - A solid or dense rock mass with practically no seams,

b) *Sheets* - A rock mass having layers or beds to 3 m thick with thin horizontal seams,

c) *Laminated* - A rock mass having thin layers of 30 to 100 cm thickness with horizontal seams with little or no gouge,

d) *Seamy* - A rock mass with many open seams in horizontal and vertical positions, and

e) *Blocky* - A rock mass, with wide open seams in all directions and filled with gouge, or which is shattered or fissured.

127 Foot Wall - The mass of rock beneath a discontinuity surface (zone).

128 **Forepoling -** Driving forepoles (pointed boards or steel rods) ahead of the excavation, usually over the last steel set erected, to furnish temporary overhead protection while installing the next set.

129 **Fracture -** A general term for any break in a rock, whether or not it causes any displacement due to the mechanical failure by stress. Fracture includes cracks, joints, faults, etc.

130 **Fracture Intercept -** It is the mean distance between successive fractures measured along an intersecting straight line. All fractures irrespective of sets are to be counted. The least intercept is to be considered in any critical direction. It is classified as F_1, F_2, F_3, F_4 and F_5 for fracture intercepts of > 200, 60-200, 20-60, 6-20, and < 6 cm respectively. This notation is used in basic geotechnical description (BGD).

131 **Full-Column-Anchored Bolts -** It is a rock bolt which has been grouted throughout its length.

132 **Gauge -** Finely graded material occurring between the walls (of a fault, joint, etc) as a result of grinding movement. Filling material such as silt, clay, rock flour and other kinds of geological debris in joints, cracks, fissures, faults and other discontinuities in rock.

133 **Gauge Length -** Gauge length is the distance between two gauge points, taken on either side of the slot of flat jack that lies in the plane normal to it.

134 **Gauge Points -** These are arbitrary points marked on both sides of the slots and are used as observation points.

135 **Grain Density (ρs) -** The mass of the grains pulverized from rock specimens or sample, after drying to constant mass at 105°C, per unit volume of the grains, that is, the density of the pore free rock fabric. The ratio of grain mass (Mg) to grain volume (Vg).

136 **Grain Mass (M_g)-** The mass of the grains from a rock specimen or sample after drying to constant mass at 105 C.

137 **Grain Volume (V_g)-** The volume of the grains pulverized from rock specimens or a sample, that is, the bulk volume minus the pore volume.

138 **Ground Arch -** The rock located immediately above a tunnel which transfers the over burden load on to the rock located on the sides of the tunnel.

139 **Ground Reaction Curve -** Shows the relationship between support pressure and radial displacements of a tunnel wall. It shows that rock pressure depends upon the tunnel wall displacement and is not a unique property.

140 **Grouting -** Grouting is a process of injecting under pressure a slurry of fluid grout or other suitable materials into the mass of a defective rock formation through a borehole to fissures and cracks in the hope that all fissures, joints and cavities will be sealed off against water in rock.

a) *Consolidation Grouting* - Fractured rockmass is grouted to increase its strength and modulus of elasticity. As a looserock mass is consolidated by grouting, this is called consolidation grouting.

b) *Curtain Grouting* - (see 79).

c) *Contact Grouting* - The gap between a dam and its foundation or between a tunnel lining and the surrounding rock mass is grouted under pressure to develop strong contact and bond between the structure and the rock mass.

d) *Stage Grouting*- A method of grouting in which a hole is drilled and grouted in a descending or ascending sequence of stages.

141 **Gunite -** A fluid mixture of fine sand, cement and water which is spray pumped through a nozzle and is used in sealing or protection work.

142 **Hanging Wall -** The mass of rock above a discontinuity surface.

143 **Hardness -** The resistance of minerals to scratching; it is a property by which minerals may be described relative to a standard scale of ten minerals known as Mohs' scale. *or*

As used for rock in drilling and bit setting.

144 **Heterogeneous (Non-Homogeneous) -** A characteristic of a medium or a field of force that signifies that the medium has the properties that vary with the position .

145 **Homogeneous Material or Medium -** Having the same properties at all points.

146 **Horizontal Rock Pressure -** The rock pressure acting in horizontal direction on tunnel support is termed as horizontal rock pressure.

147 **Hydraulic Conductivity of Fractures (K_f,L/T)-** Hydraulic conductivity of fracture is defined as the ratio between the flow velocity in the conducting fracture and the hydraulic gradient or potential gradient across it.

148 **Hydraulic Conductivity of Rock Mass(K)-** Permeability with respect to water.

149 **Hydraulic Fracturing -** Creation of a fracture in rock by applying hydraulic pressure inside a borehole.

150 **Hydraulic Gradient -** Change of pressure head per unit of distance at a given point and in a given direction.

151 **Hydraulic Monitoring -** Monitoring of pore-water pressure and discharge of groundwater in rock engineering structures. Hydraulic monitoring can give advance warning of impending failure much sooner than monitoring of deformation.

152 **Hydrostatic Pressure -** A state of stress in which all the principal stresses are equal (and there is no shear stress).

153 **Hysteresis -** A physical phenomenon met within the elastic and other behaviour of materials. When a body undergoes stress, the strain which results is a function of the stress. On releasing the stress, the strain lags behind; so the strain for any particular stress is greater while the stress is decreasing than when it is increasing. When the stress is removed altogether, a residual strain remains. This lagging behind is termed hysteresis, giving rise to an elastic hysteresis loop (a measure of internal friction).

154 **Igneous Rock -** These are the primary rocks which have been molten at sometime in their history (for example, granite, basalt, gabbro etc).

155 **Incompetent Rock -** Rock incapable of standing in underground opening or steep slopes at the surface without support.

156 **Inelastic Deformation -** The portion of deformation under stress that remains permanently even after removal of stress.

157 **Intact Rock -** A material which can be sampled and tested in the laboratory and which is free of large scale structural features, such as joints, bedding planes, shear zones, and other kinds of rock defects.

158 **Intrusive Rock -** Rock formed due to the emplacement and consolidation of magma beneath the surface of the earth in pre-existing rock.

159 **Isotropic Medium -** Having the same physical properties in all directions (said of a medium with respect to elasticity, conduction of heat or electricity or radiation of heat or light).

160 **Joint -** A break of geological origin in the continuity of a body of rock along which there has been no visible displacement. A group of parallel joints is called a set and joint sets intersect to form a joint system. Joints can he open, filled or healed. Joints frequently form parallel to bedding planes, foliation and cleavages, and may be termed bedding joints, foliation joints and cleavage joints, accordingly.

161 **Joint Alteration Number (J_a) -** The joint alteration number represents the degree of alteration of the joint surface used in classification of a rock mass by Q-system.

162 **Joint Frequency -** Number of joints per metre for a given set of joints.

163 **Joint Opening -** Mean opening of surfaces of joints of the same set.

164 **Joint Orientation -** The orientation of joints is measured by the dip and strike of joints.

165 **Joint Roughness Coefficient (JRC)-** The joint roughness coefficient is a joint parameter which accounts for roughness of a joint profile. Its value is higher for rougher joints. The value of the joint roughness coefficient can be obtained by comparing joint surfaces with typical roughness profiles. Its value may also be obtained from a tilt test on rock joints surface.

166 **Joint Roughness Number (J_r) -** The joint roughness number represents the roughness of a joint profile used in classification of rock mass by Q-system.

167 **Joint Set Number (J_n) -** is defined as the number of joint sets present in the rock mass. The joint set number is used in the classification of a rock mass by the Q-system.

168 **Joint Spacing -** Spacing between two adjacent joints of the same set.

169 **Joint Stiffness -** There are two types of joint stiffnesses as follows:

a) *Normal Stiffness of Joint (K_n, kg/cm^3) - It* is defined as the normal pressure corresponding to unit closure of the joint. The ratio between the Young's modulus of the rock material and the normal stiffness of a clean unweathered joint is generally a constant which varies as 60,25, 5 cm for continuous, discontinuous joints and cleavage planes respectively.

b) *Shear Stiffness of Joints ($K_s$kg/cm^3)* - It is defined as the shear stress corresponding to unit slip across the joint. It is generally taken as the ratio of shear strength of joint and the peak slip which is normally taken equal to 1/100 of the length of joint surface along the slip direction. It should be noted that shear stiffness of a joint is very small compared to its normal Stiffness.

170 Joint System - A group of two or more intersecting sets of joints.

171 Joint Wall Compressive Strength(JCS, kg/cm^2) - It is a parameter of a joint wall which gives the compressive strength of the as parities of the joint surface in clean unweathered joints. The joint wall compressive strength may be taken as the minimum value of uniaxial compressive strength of rock cores, otherwise it may be obtained from the correlation between the Schmidthammer number and the uniaxial compressive strength.

172 Joint Water Reduction Factor (J_w)- The parameter J_w is a measure of water pressure which has an adverse effect on shear strength of joints due to reduction in normal stress. Water may, in addition, cause softening and possible out wash in the case of clay filled joints.

173 Karst - A geologic setting where cavities are developed in massive limestone beds by solution or by flowing water. Caves and even underground river channels are produced into which surface run-off drains, and often results in the land above being dry and relatively barren.

174 Laminar Flow - The flow of a liquid in which the movement at any fixed point is continuous, steady and constant.

175 Landslides - The relatively perceptible downward and outward movement of slope-forming materials, such a-s rock, soil, artificial fill, or a combination of these materials with respect to the original mass. Also, earth and rock that become loosened from a hill side by the water of snow or an earthquake and which slides or falls down the slope.

176 Layer Thickness - It is the mean thickness of a layered zone of a rock mass. It is classified as L_1, L_2, L_3,L_4, L_5 for layer thicknesses of >200, 60-200, 20-60, 6-20 and < 6 cm respectively. This notation is used in basic geotechnical description(BGD).

177 Lineation - Lineation is any one-dimensionalfeature in a rock shown on a rock surface. It may arise in any of the following ways:

a) By a linear-parallel arrangement of minerals, either by growth or mechanical orientation;

b) By the intersection of a planar structure with the rock surface;

c) By the intersection of two planar structures such as bedding and cleavages;

d) By the development of a series of small parallel packers in a planar structure such as micro folds, and

e) By the deposition of elongated particles in a preferred orientation during sedimentation.

178 **Liquefaction -** The change in phase of a substance (say, a mass of a saturated sand) to the fluid state (say, sand as a loose, moving pouring body). A saturated non-cohesive soil mass can be in a fluid state if no intergranular pressure exists within it. -Such a fluid state is commonly called liquefaction.

179 **Liquid Limit (W1) -** The minimum moisture content at the point between the liquid and the plastic states of clay, or

The water content expressed as a percentage of weight of oven-dry soil, at the boundary between liquid and plastic states of consistency of soil.

NOTE - For the purpose of determination of liquid limit, it is defined as the water content at which a part of soil, cut by a groove of standard dimensions, will flow together for a distance of 12 mm under the impact of 25 blows in a standard liquid limit apparatus, or as the water content of a soil paste, prepared in a specified mould, into which a cone of specified dimensions and weight penetrates by 25 mm which dropped on to the paste in a specified manner.

180 **Lithology -** The physical character of a rock.

181 **Long-Term Rock Pressure -** This is the ultimate rock pressure on the supports in under ground openings.

182 **Loosening Pressure -** Rock pressure exerted at supports by dead weight of loosened rock mass above a cavity.

183 **Lugeon-** A water intake of 1 l/m/min at an injection pressure of 10 bars, that is, 1035 kN/m^2.

184 **Machine Stiffness -** The stiffness of a compression testing machine is defined as the ratio of force across the loading platens to the closure of platens after reducing the force to zero. To obtain complete stress-stain

curves of rock, it is essential that machine stiffness is more than post-peak stiffness of the test specimen, otherwise failure of the specimen will occur in violent manner.

185 **Macrofractures -** These are cracks in rock wider than 0.1 mm. They may be up to several metres or more in length.

186 **Mathematical Model -** The representation of a physical system by mathematical expressions from which the behaviour of the system can be deduced with known accuracy.

187 **Mass Movement -** Unit movement of a portion of land surface as in creep, landslide or slip.

188 **Mass-Wasting -** The slow down slope movement of rock debris. A general term for a variety of processes by which large masses of earth materials are moved by gravity either slowly or quickly from one place to another.

189 **Massive Rock -** The rock mass is massive if the strength of the bond across partings or joints is comparable to the rock strength.

190 **Micrograph -** A micrograph is obtained by an electron microscope and shows the structure of particles of soil or rock.

191 **Microseismic Noise -** When rock material is overstressed and starts fracturing, specially in underground openings and rock slopes, micro cracks develop giving rise to propagation of microseismic pulses which may be detected and recorded through geophones as 'microseismic noise' or acoustic emission. Rock burst is an example of microseismic noise or acoustic emission.

192 **Modulus of Deformation -** See deformation modulus.

193 **Modulus of Elasticity (E) -** See axial Young's modulus.

194 **Modulus Ratio -** This is used to classify rock material and is defined as the ratio between the Young's modulus and the uniaxial compressive strength. The higher the value of the modulus ratio, the more brittle is the rock. The rock material is classified as high, medium and low modulus ratio for modulus ratios of > 500,500-200 and < 200 respectively.

195 **Modulus Reduction Factor (MRF)-** The modulus reduction factor is defined as the ratio between static elastic modulus of rock mass (E orestatic) obtained from in-situ tests and theelastic modulus of rock matter (Er) obtained from laboratory test.

196 **Modulus of Subgrade Reaction -** It is defined as the ratio of normal pressure on the foundation and the corresponding settlement.

197 **Mohr Circle of Stresses/Strain -** A graphical representation of the components of stress/strain acting across the various planes at a given point, drawn with reference to axes of normalstress/strain and shear stress/strain.

198 **Mohr Envelope -** The envelope of a sequence of Mohr circles representing stress conditions at failure for a given material.

199 **Mohs Hardness Scale -** A scale of relative hardness of minerals arbitrarily reading from 1to10.

200 **Mud Springs -** When a joint strikes the ground water table below very soft or liquid(sloppy) ground, a spring will be formed. If mud comes out of the spring, it is called a mud spring.

201 **Mylonite -** A compact, chert like rock without cleavage but with a streaky or banded structure produced by the extreme granulation and shearing of rocks which have been pulverized and rolled during over thrusting or by the action of intense dynamic metamorphism, in general. Mylonite may also be described as a microbreccia with flow texture

202 **Neutral Pressure (u, F/L^2) -** Pressure of water in the pores (voids) of a saturated medium of soil and rock. Also known as pore water pressure.

203 **Normal Stress -** The stress in a rock normal (perpendicular) to the shear stress.

204 **Outbursts of Gas -** In an opening, a rock mass may separate suddenly from the face and is crushed. This process may be accompanied by release of significant quantities of gas. The gases released by outbursts are most commonly methane carbon dioxide and nitrogen. Gas outbursts commonly take place in coal mines and can also take place in shales, etc.

205 **Outcrop -** That part of a stratum which appears at the surface. *or*

Actual exposure of bed rock.

206 **Over-Coring -** A process of drilling around a previously installed gauge within a borehole to relieve the stresses around the gauge.

207 **Over-Toppling -** In some slopes, failure takes place not by sliding of rocks but by over-toppling of blocks of rocks. This type of failure occurs generally in steep slopes in thinly bedded rocks.

208 **Particle Velocity -** As a seismic wave propagates, it causes a particle of rock or soil to oscillate around its original position. The local velocity of -motion of the particle is known as particle velocity. The ratio of particle velocity to the wave velocity gives the value of dynamic strain.

209 **Pay Line -** See B line.

210 **Peak Shear Strength -** Maximum shear strength along a failure surface.

211 **Percolation -** The movement of gravitational water through soil.

212 **Perma-frost -** Permanently or perenially frozen ground.

213 **Permeability (k, L/T) -** Permeability is defined as that property of a porous material that permits the passage or seepage of fluids such as water or oil or gas (air) through its interconnecting voids. The overall permeability of a rock mass is denoted by K_c and is called the permeability of equivalent continuum.

214 **pH Value -** The negative logarithm of the hydrogen ion activity. For example pH 7 indicates a hydrogen ion concentration (activity) of 10^{-7} mole/litre.

215 **Piezometer -** An open or closed tube or other device installed downward from the ground surface and used to measure the level to which the water from a given aquifer will rise under its full head.

216 **Piezometric Surface -** The surface at which water will stand in a series of piezometers.

217 **Pilot Tunnel -** A small tunnel excavated over the entire length or over part of a tunnel to explore ground conditions and assist in final excavation.

218 **Pit -** An excavation in the surface of the earth from which ore is obtained as in the large open pit mining or an excavation made for test purposes.

219 **Plane of Weakness -** Planes in rocks that affect its structural properties. The planes may be the result of joints, fractures, faults, bedding or partings.

220 **Plane Wedge Failure -** It is defined as the failure which occurs when a geological discontinuity such as a bedding plane, strikes parallel to the slope face and dips into the excavation at an angle greater than the angle of friction.

221 **Plastic Deformation -** Deformation that remains after the load causing it is removed. It is the permanent part of the deformation beyond the elastic limit of a material resulting in plastic strain, plastic flow and irrecoverable deformation.

222 **Plastic Limit (W_p) -** The water content at the lower limit of the plastic state of a clay. It is the minimum water content at which a soil can be rolled into a thread 3 mm in diameter without crumbling.

223 **Plastic Zone -** See broken zone.

224 **Point Load Lump Strength Index (I_1, F/L^2) -** It is the point load strength of a rock lump tested in point load tester.

225 **Point Load Strength Index (I_s, F/L^2) -** It is the point load strength of a rock core tested in point load tester. It is defined as the ratio of peak load at failure to the square of diameter of core. The standard size of the core is Nx size that is about 54 mm.

226 **Poisson Ratio (g) -** The negative of ratio of the slope of axial stress strain curve to the slope of the axial stress-diametrical strain curve for a cylindrical specimen subjected to uniaxial compression.

227 **Pore Volume (V_p, L^3) -** The volume of all pores contained within the gross external dimensions of a rock specimen or sample.

228 **Pore Water Pressure -** See natural pressure.

229 **Porosity (n)-** The volume of voids in a rock specimen expressed as a percentage of the gross volume (VB) of the specimen.

230 **Portal -** The entry or exit point of a tunnel if it meets the ground surface.

231 **Pre-splitting -** See smooth blasting.

232 **Pressure Bulb -** The zone of stresses below a foundation, outside of which stresses are less than a limiting value. A 10 percent pressue bulb is defined as a pressure bulb or zone of stresses in which maximum stress is more than 10 percent of the foundation pressure.

233 **Primary Lining -** The lining initially placed inside a tunnel or shaft, usually to support the excavation. The primary lining may be of wood or steel sets with steel or wood lagging or rock bolts and shotcrete.

234 **Primitive Stress -** The ground is in a state of equilibrium before excavation of a tunnel or any underground opening. At this stage, the stresses at any point within the ground are termed as 'primitive', 'primary' or 'pre-excavation' stresses.

235 **Quarry -** An excavation in the surface of the earth from which stone is obtained for crushed rock or building stone.

236 **Quasi-Elastic -** Quasi as if, as though it were, seemingly almost elastic, that is considered as elastic for practical purposes.

237 **Radius of Influence (e, L)-** The 'radius of influence' is an empirical concept used in a bore hole permeability test. It is the distance from the borehole at which the influence of the test on the piezo metric head is no longer perceptible. Generally, one may consider that the radius of influence is between 100 and 1000 times the radius of the test bore hole. (The radius of influence is greater in more permeable ground).

238 **Raft Foundation -** A raft is a continuous slab of RCC connecting all columns and walls.

239 **Redox Potential -** The stability of an element in a state of oxidation depends on the energy involved either in adding or subtracting electrons, and a quantitative measure for this is given by the redox potential.

A redox reaction is an oxidation-reductionone. If, in a cell, oxidation is produced at the anode and reduction at the cathode, the potential necessary is the redox potential. It is actually measured relative to a standard 'hydrogen electrode' taken as zero; this consists of platinum over which hydrogen is bubbled so as to produce a standard

concentration of hydrogen ions. Redox potential is a measure of corrosion of anchor bars, cables, etc.

240 **Relaxation -** Rate of reduction of stress in a material due to creep. An alternate term is stress relaxation.

241 **Residual Shear Strength -** Shear strength along a failure surface after a large displacement.

242 **Residual Stresses -** Residual stresses are defined in the sense of the theory of elasticity as 'locked-in' stresses associated with the previous rheological history of the rock. They may exist where viscoelastic effects of erosion have not completely relaxed. A viscoelastic substance cannot retain residual stresses indefinitely, but some material possessing a yield stress can do so.

243 **Resonance -** Where a small periodic force is applied to a system capable of oscillation, the system is usually set into forced oscillations of small amplitude and, as the frequency, f, of the excitant force approaches the natural frequency of the system, fo' at which point the system is said to be in resonance with the excitant force.

244 **Rheology -** Science dealing with the flow or deformation of matter. The study of time dependent strain in both solids and liquids. Sometimes, rheology describes the study of all types of deformation, elastic and viscous, particularly the plastic flow of solids and flow of non-Newtonianliquids.

245 **Rock -** Any naturally formed aggregate of mineral matter occurring in large masses or fragments.

246 **Rock Anchor -** A steel rod or cable installed in a hole in rock to resist pull or shear force in principle same as the rock bolt, but generally used for rods longer than about four metres.

247 **Rock Bolt -** A steel rod placed in a hole drilled in rock used to reinforce the rock together. One end of the rod is firmly anchored in the hole by means of a mechanical device and/or grout, and the threaded (projecting) end is equipped with a nut and plate which bears against the rock surface. The rod can be pretensioned.

248 **Rock Burst -** Sudden explosive like release of energy due to the failure of a brittle rock of high strength in an underground opening.

249 Rock Fall - The relative free falling of newly detached segments of bed rock of any size, from cliff, steep slope, cave or arch.

250 Rock Mass- Rock mass is in-situ rock which has been rendered discontinuous by systems of structural features such as joints, faults and bedding planes.

251 Rock Mass Quality (Q)- A numerical index depending upon the rock mass quality and geological conditions, used to classify a rock mass. It is equal to $(RQD/J_n)\ (J_r/J_a)\ (J_w/SRF)$,

where

RQD= rock quality designation

J_n = joint set number,

J_r = joint roughness number,

J_a = joint alteration number,

J_w = joint water reduction factor and

SRF = stress reduction factor.

252 Rock Mass Rating (RMR)- A numerical index depending upon the quality of a rock mass and geological conditions, used to classify a rock mass. It is the sum of ratings for uniaxial compressive strength, spacing, condition of joints, ground water conditions, RQD and joint orientation.

253 Rock Material - This is the smallest element of rock not cut by any fracture; there are always some micro-fractures in the rock material.

254 Rock Pressure (Vertical) - The rock pressure acting vertically on the tunnel supports is called vertical rock pressure.

255 Rock Quality Designation (RQD) - This IS the percentage of sound cores recovered in pieces greater than or equal to 10 cm length with respect to the total core run.

256 Rock Reinforcement - The placement of rock bolts, rock anchors or tendons at a fairly uniform spacing to consolidate the rock and reinforce the rock's natural tendency to support itself. It is also used in conjunction with shotcrete on rock surface.

257 **Rock Slide -** The downward, usually rapid movement, of newly detached segments of the bedrock sliding on bedding planes, joint or fault surfaces or any other plane of separation.

258 **Rock Weathering -** The physical disintegration of rocks at or near the earth surface due to composition of minerals caused by the climatic change.

259 **Roof Truss -** The concept of roof truss support of openings in a rock mass is based on the development of a truss in the form of rock bolts and cable supports. Inclined holes are used at the ends which are tied up by a cable. The compression produced by the rock bolts and cables develops the effect of a truss within the rock mass in the opening.

260 **Rotational Side -** A relative displacement of points on opposite sides of a fault, measured on the surface of the fault, a minor fault or a slide.

261 **Round -** A set of holes drilled and charged in a tunnel or quarry which are fired instantaneously or with short-delay detonators.

262 **Rupture -** Failure of a material with development of fractures or shear planes. Deformation characterized by loss of cohesion.

263 **Safe Blasting Criterion -** Particle velocity has been found to be the best criterion for predicting damage to structures due to blasting vibrations. It has been recommended that particle velocity near any structure should not be allowed to exceed 50 mm per second.

264 **Sagging -** Usually occurs in sedimentary rock formations as separation and downward bending of sedimentary beds in the roof of an underground opening.

265 **Sample -** The rock submitted to the laboratory for testing.

266 **Scabbing -** Fracturing of rock in the form of slabs, due to interference between the wave front of an incident compressive wave and its reflection from rock surfaces.

267 **Scaling -** Removing loose pieces of rock in a tunnel after blasting.

268 **Schistosity -** The variety of foliation that occurs in coarse-grained metamorphic rocks and is generally the result of the parallel arrangement of platy and ellipsoidal mineral grains within the rock substance.

269 **Sealed Distance -** The sealed distance is a term used in predicting the effect of blasting vibrations on the buildings and other structures on the surface. Generally, it is taken to be D/W1/2,where D is the distance from the source of blasting to the structure under consideration and Wis the weight of explosive per delay.

270 **Seamy -** A rock mass with many thin layers.

271 **Secondary Lining -** The finally placed, or permanent structural lining of a tunnel which maybe of concrete, steel or masonry.

272 **Secondary Stress (Induced) -** Creation of an underground opening modifies the stress distribution around the opening. These modified stresses are known as the induced, secondary or post-excavation stresses.

273 **Sedimentary Rock-** Rocks formed by the accumulation of sediments derived from the breakdown of earlier rocks by chemical precipitation, or by organic activity, for example, sandstone, limestone, shale, etc.

274 **Self-Supporting Opening -** In good quality rock masses, an opening may be made without using any kind of support system and it will stand for long periods of use. Such openings are called self-supporting openings.

275 **Shaft -** Generally, a vertical or near vertical excavation driven downward from the surface as access to tunnels, chambers or other underground workings.

276 **Shear Failure (Failure by Rupture) -** Failure in which movement is caused by shearing stresses in a rock mass.

277 **Shear Modulus (Modulus of Rigidity) -** The ratio of shear stress to shear strain for a material determined either from the slope of the tangent or of the secant of a stress-strain curve.

278 **Shear Strength of a Rock Mass -** The maximum resistance of a rock mass (including joints) to shearing stresses.

279 **Shear Strength of Rock Material -** The maximum resistance of a rock material (excluding joints) to shearing stresses.

280 **Shear Zone -** A zone in which shearing has occurred on a large scale so that the rock is crushed and brecciated.

281 **Shield -** A steel cylinder with open or closed face equal to the tunnel diameter for tunnel excavation in soft grounds.

282 **Shock Waves -** A shock wave is an inelastic wave. In fractured rock, the mass tangential modulus of elasticity increases with increasing strain. Any pulse will then tend to acquire a steep front and travel faster than the elastic waves. This phenomenon gives rise to a shock wave which has a great damaging potential or reflection from an open surface.

283 **Short-Term Rock Pressure -** Pressure generated immediately after excavation.

284 **Shotcrete -** A pneumatically applied concrete mix projected on an uneven rock surface. Shotcrete provides an effective protection of rock against weathering.

285 **Silt -** The term silt applies to unconsolidated material finer than sand and coarser than clay. In the non-technical sense, silt is the muddy, fine sediment carried and laid down by rivers or by the ocean in bays and harbours.

286 **Sink Hole -** Any slight depression in the land surface, specially one having no outlet, one of the hollows in limestone regions (limestone sinkholes) often communicating with a cavern or subterranean passage so that water running into it is lost.

287 **Size Effect or Scale Effect -** The strength of rocks decreases with increasing size of the specimen particularly under tensile stresses. This affect is known as size effect or scale effect.

288 **Slabbing -** The creation of axial cracks due to uniaxial compressive stresses, results in slabs of rock popping out into the cavity.

289 **Slake Durability Index (I_d) -** The percentage ratio of the final dry mass to the initial dry mass of a sample after being subject to one10 minute slaking cycle in a slake durability apparatus.

290 **Slaking -** When an air-dried or oven-driedsample of fine particled soil is placed in water, the soil slakes. The force of surface tension draws the water into the voids and compresses the air trapped inside. The pressure in the air may become so high that the corresponding tension in the soil causes the slaking.

291 **Slickenside -** A polished and smoothly striated surface that results from friction along a fault plane.

292 **Slip Lines -** Orthogonal curves whose directions at any point bisect the angles between the principal axes at that point.

293 **Smooth Blasting -** Smooth blasting is used to minimize damage to the rock mass due to blasting vibrations. It is done by drilling closely spaced drill holes and blasting them by light charge.

294 **Soil -** All unconsolidated earth material of whatever origin that overlies bedrock, that has been in any way altered or weathered.

295 **Spalling Rock -** A rock mass under stress that yields thin slabs or wedges of rock by rapid failure. Slabs commonly form parallels to the walls or arch of an opening in rock.

296 **Specific Gravity (G_m) -** Ratio of weight of a given volume of dry rock to the weight of equal volume of distilled water at a standard temperature.

297 **Specimen -** The portion of the sample upon which the test is to be performed.

298 **Spring Line -** The place on the side of a tunnel where the tunnel starts curving into the arch.

299 **Squeezing Ground Condition -** A situation where a rock tries to squeeze inside the cavity soon after excavation, both in horizontal and vertical directions (any rock can behave as squeezing rock if in-situ stresses are high).

300 **Squeezing Pressure -** Rock pressure exerted on supports by squeezing ground.

301 **Stage Grouting -** See grouting.

302 **Stand Up Time -** This is the time lapse between excavation and the instant when the first rock piece falls from the roof, in a newly excavated tunnel or opening.

303 **Stick-Slip Oscillations -** When a rock mass is sheared along smooth or rough joint surface, oscillations in the shear force vs slip curve may be observed. These are called stick-slip oscillations. Though the rate of

shearing is constant, the actual slip takes place in jerks. While there is no motion, it is called stick and when motion starts, it is called slip. The total motion is called stick-slipmotion.

304 **Storage Co-efficient (S) -** It is the change in the discharge out of an aquifer per unit change of head.

305 **Strain Ellipsoid -** The representation of the strain in the form of an ellipsoid into which a sphere of unit radius deforms and whose axes are the principal axes of strain.

306 **Strain Energy Release Rate -** It is the rate of strain energy released per unit area of the excavated surface in the underground minor tunnel openings. If the strain energy release rate is more than a limiting value, rock burst is likely to occur.

307 **Strain Hardening -** If upon loading beyond the yield point, the stress-strain curve continues to rise within the inelastic domain above the yield point, the material is said to be strain hardened.

308 **Strain Softening -** During uniaxial or triaxial testing of rocks, it is generally observed that strength decreases after certain strain. This is known as strain softening.

309 **Stratum -** A layer or bed of rock or soil.

310 **Strength Anisotropy Index -** The ratio of the corrected point load strength indices for tests, perpendicular and parallel to planes of weakness in samples of an intact rock.

311 **Stress Concentration Factor -** Stress concentration takes place when a cavity is excavated in a rock mass. The stress concentration factor is defined as the ratio of tangential stress at a particular point along the periphery and the initial stress before excavation at that point. The higher the stress concentration factor, the greater are the chances of failure of the rock mass or rock burst.

312 **Stress Ellipsoid -** The representation of the state of stress in the form of an ellipsoid whose semi-axes are proportional to the magnitude of the principal stresses and lie in the principal directions. The coordinates of a point P on this ellipsoid are proportional to the magnitudes of the respective components of the stress across the plane normal to the direction OP, where O is the centre of the ellipsoid.

313 Stress Reduction Factor (SRF)- The parameter SRF is a measure of:

(a) loosening pressure in the case of excavation through shear zones and clay bearing rock masses,

(b) rock stress q_c/σ_1 in a competent rock mass where qc is uniaxial compressive strength of rock mass and σ_1 is the major principal stress before excavation, and

(c) squeezing or swelling pressure in incompetent rock masses. SRF, hence, can be regarded as a total stress parameter.

314 Strike - It is the direction of a line formed by the inter-section of the structural surface(for example a bedding or fault plane) and a horizontal plane.

315 Subsidence - Settlement of ground above the workings of underground operations.

316 Support - Structure or structural feature built into an underground opening for maintaining its stability.

317 Surface Energy - The surface of a crack is supposed to possess surface energy per unit area, associated with rupturing of atomic bonds when a crack is formed. A crack can propagate only when the strain energy release rate is more than the surface energy of the crack.

318 Surface Porosity - It is the porosity of voids on a given surface of rock. It is defined as the area of voids to the total surface area of rock material.

319 Suspension Bolt - Rock bolts which are used to suspend weak rock layers or a fractured rock mass are known as suspension bolts. These bolts are anchored into the competent thick rock layer or rock mass.

320 Swelling - Swelling can be defined as a time-dependent volume increase of the natural ground caused by stress changes, increase in water content or by a combination of both:

a) *Swelling Pressure Index (icc)* - The maximum axial stress recorded upon a radially and axially confined specimen after it is fully saturated;

b) *Swelling Strain Index (sru)* - The maximum increase in axial strain, expressed as a percentage, of a radial confined specimen under a standard axial load upon saturation; and

c) *Unconfined Swelling Strain (svc)* - The maximum increase in strain, expressed as a percentage, in a dimension of an unconfined specimen upon saturation.

321 Talus - Fragments which are broken off by the action of the weather from the face of a steep rock, accumulate at its foot, forming a sloping heap called talus.

322 Tectonic Creep - Fault creep of tectonicorigin, also called slippage.

323 Tensile Strength (q_t)- It is ultimate strength of a material subjected to a tensile loading. Tensile strength is not a unique property of rock and depends very much upon the type of the test.

a) *Uniaxial Tensile Strength* - Tensile strength of rock specimen subjected touniaxial tensile stress.

b) *Flexural Strength* - Tensile strength of a rock layer or beam subjected to bending moment. Flexural strength is obtained by a beam test on rocks and is significantly higher than the uniaxial tensile strength.

c) *Brazilian Tensile Strength* - Tensile strength obtained from the Brazilian test on rock disc.

324 Tension Crack - Vertical cracks which occur on the top terrace of a slope which is under distress. These cracks are called tension cracks, as they develop due to existence of tensile stresses in that region. Tension cracks can also occur along the slope but this is usually rare.

325 Terrace - Any level topped surface, with a steep escarpment, whether it be solid rock or loose material. It is step like in character.

326 Texture - It is the relationship between the grains of minerals forming a rock.

a) *Porous* - Rock material with cellular structure and large voids;

b) *Fragmental* - Rock material having fragments of minerals which are loosely packed;

c) *Granitoid*- Rock material with grains large enough to be readily recognized average grain -granite;

d) *Porphyritic* - Rock with large crystals in fine grained mass; and

e) *Dense* - Rock with grain structure too small to identify with the naked eye.

327 Thermal Stress - Internal stress, caused in part by uneven heating.

328 Three-Dimensional Wedge Failure (of Slopes) - When two discontinuities strike obliquely across the slope face and their line of intersection day lights in the slope face, the wedge of rock testing on these discontinuities will slide down along the line of intersection, provided this is greater than the angle of friction.

329 Throw - The projection of broken rock during blasting or

In measuring the horizontal or vertical separation, the throw of the fault is the vertical component of the dip separation.

330 Tight - Rock remaining within the minimum excavation lines after completion of a blasting round.

331 Toughness - Extent to which a material absorbs energy without fracture.

332 Trench - Usually a long, narrow, near vertical sided cut in rock or soil such as is made for utility lines.

333 Tunnel - A passage in rock or soil open at both ends.

334 Tunnel Supports - A support system used in a tunnel is known as a tunnel support. These are of two types:

a) Stiff Supports - These are supports which do not deflect Significantly with increase in rock pressure and are known as rigid or stiff rock supports such as concrete linings or steel supports of every heavy section; and

b) Flexible Support - Those supports which deflect significantly with increase in rock pressures are known as flexible supports such as steel supports of thin section with gravel packing and shotcrete. The advantage of a flexible support system is to dissipate the strain energy stored in the rock mass by allowing squeezing of rock mass.

335 Ultimate Rock Pressure - Pressure which will eventually develop on supports during the life time of an opening.

336 Unconfined Compressive Strength - See uniaxial compressive strength.

337 Unconfined Swelling Strain (Svc)- The maximum increase in strain, expressed as a percentage, in a dimension of an unconfined specimen upon saturation.

338 Undulating Rock Profile - If the profile of the rock mass below a soil cover is undulating, it is called an undulating rock profile. This may happen in soluble rocks.

339 Uniaxial Compressive Strength (q_c, F/L^2) - The maximum uniaxial compressive load carried by a right cylindrical specimen of rock divided by the cross-sectional area of the sample. It is classified as S_1, S_2, S_3, S_4,S_5 for uniaxial compressive strengths of 2000, 600-2000, 200-600,60-200 and <60 kg/cm^2, respectively. This notation is used in the basic geotechnical description(BGD).

a) *Unit Weight (gFL^{-3})*

b) *Dry Unit Weight - g_d (FL^{-3})* - The weight of even dry rock per unit of total volume of rock.

c) *Saturated Unit Weight - g_{sat}* (FL^{-3}) - The unit weight of a rock material when saturated.

340 Unsupported Span - It is the distance between face of excavation and first line of support or the width of the opening whichever is minimum. It affects the stand-up time.

341 Uplift Pressure - Either the upward force on a dam base due to water pressure in the foundations or the upward heaving of earth caused by the escape of water under high pressure from a dam or other confined area.

342 Vesicles - Voids formed due to emanation of gases in flows of volcanoes.

343 Virgin Rock Stresses - See Primitive stress.

344 Void Index (I_v) - Void ratio defined as the mass of water contained in a rock sample after a one hour period of immersion, as a percentage of its initial desiccator-dry mass.

345 **Volumetric Joint Count (J_v)-** It is the total number of joints in a unit cube of rock mass of 1 m^3 volume.

346 **Water, Interstitial -** Water that exists in the interstices or voids in rock, soils or other kinds of porous media.

347 **Water, Meteoric -** Water that is in or derived from the atmosphere. The term has been used in various ways, sometimes to include all sub-surface water of external origin and sometimes to include only that derived by absorption, excluding specially the connate ocean water.

348 **Wave Front -** The surface which is the locus of all points, having their motion in identical phase propagating in a wave, the direction of propagation being perpendicular to the wavefront.

349 **Weathering -** The process of rock breakdown and decomposition instigated by external agencies, such as wind, rain, change in temperature, plants, etc. Two main types exist, namely, mechanical (physical) and chemical. The former involves break-up processes, the latter chemical alteration. Weathering together with subsequent transportation comprise erosion.

350 **Yield Stress -** The stress at which strain increases without accompanying increase in stress. It is an indication of maximum stress that can be developed in a material without causing plastic deformation. It is the stress at which a material exhibits a specified permanent deformation and is a practical approximation of elastic limit.

351 **Yielding Supports -** Supports capable of undergoing substantial deformation so as to modify stress distribution around the supports.

352 **Young's Modulus -** See axial Young's modulus.

353 **Zone of Weathering -** That layer of superficial deposits subject to weathering and broadly coinciding with the belt of soil water.

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